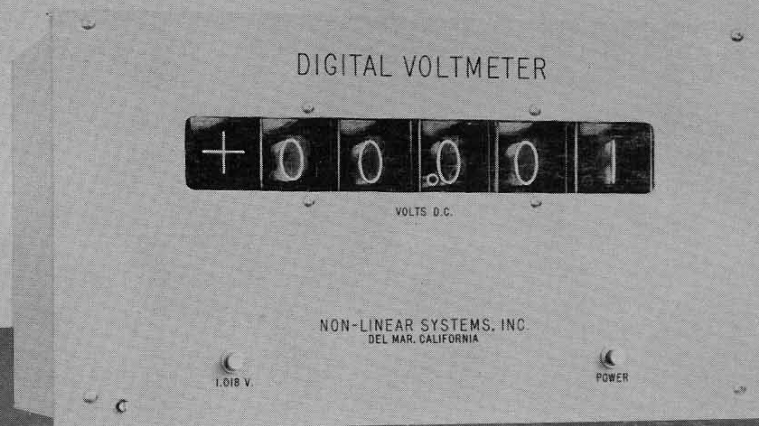


# THE DIGITAL VOLTMETER MODEL —



*operation and service manual*

NON-LINEAR  
SYSTEMS  
INC.  
Del Mar Airport  
Del Mar, California

## FOREWORD

TO:

*Convair, Pomona, California*

*Serial Number 6.154*

In developing the digital voltmeter, Non-Linear Systems, Inc., has utilized circuits having characteristics suitable to the greatest number of applications. However, final evaluation of a specific instrument must rest with you --the user. From your day-to-day experience of its advantages and limitations will emerge the most valid estimate of what characteristics are to be desired, what components or functions should be modified, and the relative importance of such modification.

It is our sincere desire to use the experience and suggestions of our customers to the utmost in order to increase the versatility and usefulness of our instruments. Your comments are always invited, and will receive our most careful consideration.

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NON-LINEAR  
SYSTEMS  
INC.  
Del Mar Airport  
Del Mar, California

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Table I Digital Voltmeter Specifications.

MODEL	RANGE		ACCUR- ACY *	INPUT RESIST- ANCE (Megohms)	SPEED **	CONTROLS		REFERENCE
	FROM	TO				DECIMAL	POLARITY	
200	.01	.99	1%FS	100	200	Fixed	Fixed	Internal
300	.001	.999	0.1%FS	100	133	Fixed	Fixed	Internal
301	.001	.999	0.1%FS	100	133	Fixed	Automatic	Internal
302	.001	99.9	0.1%FS	11	133	Automatic	Fixed	Internal
319	.001	99.9	0.1%FS	11	133	Automatic	Automatic	Internal
400	0.001	9.999	0.01%FS	100	100	Fixed	Fixed	Internal
401	0.001	9.999	0.01%FS	100	100	Fixed	Automatic	Internal
402	0.001	999.9	0.01%FS	11	100	Automatic	Fixed	Internal
403	00.01	99.99	0.01%FS	11	100	Fixed	Automatic	External
411	00.01	99.99	0.01%FS	100	100	Fixed	Automatic	Internal
419	0.001	999.9	0.01%FS	11	100	Automatic	Automatic	Internal
500	00.001	99.999	0.01%MV	100	80	Fixed	Fixed	Internal
501	00.001	99.999	0.01%MV	100	80	Fixed	Automatic	Internal
502	00.001	999.99	0.01%MV	11	80	Manual	Fixed	Internal
503	00.001	999.99	0.01%MV	11	80	Manual	Automatic	Internal
519	00.001	999.99	0.01%MV	11	80	Automatic	Automatic	Internal

\* ACCURACY: FS = Full scale of range in which instrument is operating.  
MV = Measured voltage (the input voltage being measured).

\*\* SPEED: Zero to full scale readings per minute.

OPTIONAL FEATURES: (letter added to model number - - e. g. 519-P).

P = Built-in Recording Controls.

R = Remote Indicator and Cables.

C = Remote Cable.

M = Number of Readings Per Minute Doubled.

O = Output Plugs For Remote Indicator or Buffer Relays.

X = Special.

## SECTION 1 ————— DESCRIPTION

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### INTRODUCTION

Digital voltmeters manufactured by Non-Linear Systems, Inc., are designed for rapid and accurate measurement of a wide range of direct current voltages.

The measured voltages are displayed as a single horizontal line of easily-read, illumined numerals. An illumined polarity sign prefixes the numerical display of the measured voltages, and an illumined decimal point is provided between particular numerals as required by the voltage measurement being made. Records of the digital voltmeter indications can be made by suitable connection of electric printers or other recording systems. Many special applications of the digital voltmeters are possible.

### SPECIFICATIONS

Digital voltmeters are available in the variety of standard models listed in Table I. Digital voltmeter Model 519-P provides for a voltage measurement of 5 digits including automatic polarity and two-position automatic decimal point display, as well as provisions for connection to an external printer. This manual describes operation and service procedures for the Model 519-P. Users of models other than the 519-P will ignore operation and service instructions not applicable to their particular instrument. In addition to the wiring diagram of the basic digital voltmeter system supplied in this manual as Figure 13, each customer is furnished a wiring diagram describing the particular instrument purchased.

## COMPONENTS

The extensive use of modern etched circuit techniques in the construction of these digital voltmeters permits extremely rapid inspection and maintenance. Etched circuit boards containing components having associated functions plug into a chassis assembly and are interchangeable with boards from other digital voltmeters of the same model number.

### ----CHASSIS ASSEMBLY

The chassis assembly consists of a front panel, frame, etched circuit chassis board and a numerical readout. The front panel contains the "POWER" switch, "1.018V" calibrate switch and a slotted calibration rheostat shaft. The numerical readout, with polarity and decimal indications, is mounted on the rear of the front panel and the display is in view when facing the digital voltmeter.

The lower rear portion of the frame contains a fuseholder, alternating current input plug, direct current input plug, and nameplate data. The chassis etched circuit board contains circuit paths between the various plugs and components mounted thereon. A 28-volt transformer, power transformer, filter condenser and a 6AS7G power supply tube are mounted on the top right hand side of the chassis etched circuit board. (See Figure 1 on page 8.) A chopper and a certified miniature standard cell are mounted on the extreme left side of the chassis. The standard cell certificate is included herein as Figure 3 on page 10. Figure 2 on page 9 shows the bottom view of the chassis etched circuit board.

### ----PLUG-IN UNITS

A series of front and rear plugs are mounted between the components along the right and left sides of the chassis and on top of the chassis etched circuit board. These plugs accept vertically-positioned plug-in boards perpendicular to the front panel. (See Figure 1.) Reading from right to left, these etched circuit boards are designated as: (1) Power Supply, (2) Decimal-polarity, (3 through 7) Decades, (8) Amplifier, and (9) Range Unit.

# SECTION 1 ————— DESCRIPTION

Notches in the lower edge of the plug-in boards accept correspondingly located pins in the chassis plugs to insure correct alignment of plug clips and contact tabs on the boards. Further the notch and key pin locations prevent inadvertent insertion of a board in an improper position on the chassis. All decade plugs and boards are keyed alike. However, care must be exercised to insert the decade boards in the proper order of increasing balancing resistances from the right to left side of the chassis.

For purposes of circuit tracing, all plug-in board contact tabs are identified by a unique symbol made up as shown by Table II.

Table II Identification of Contact Tabs on Plug-in Boards.

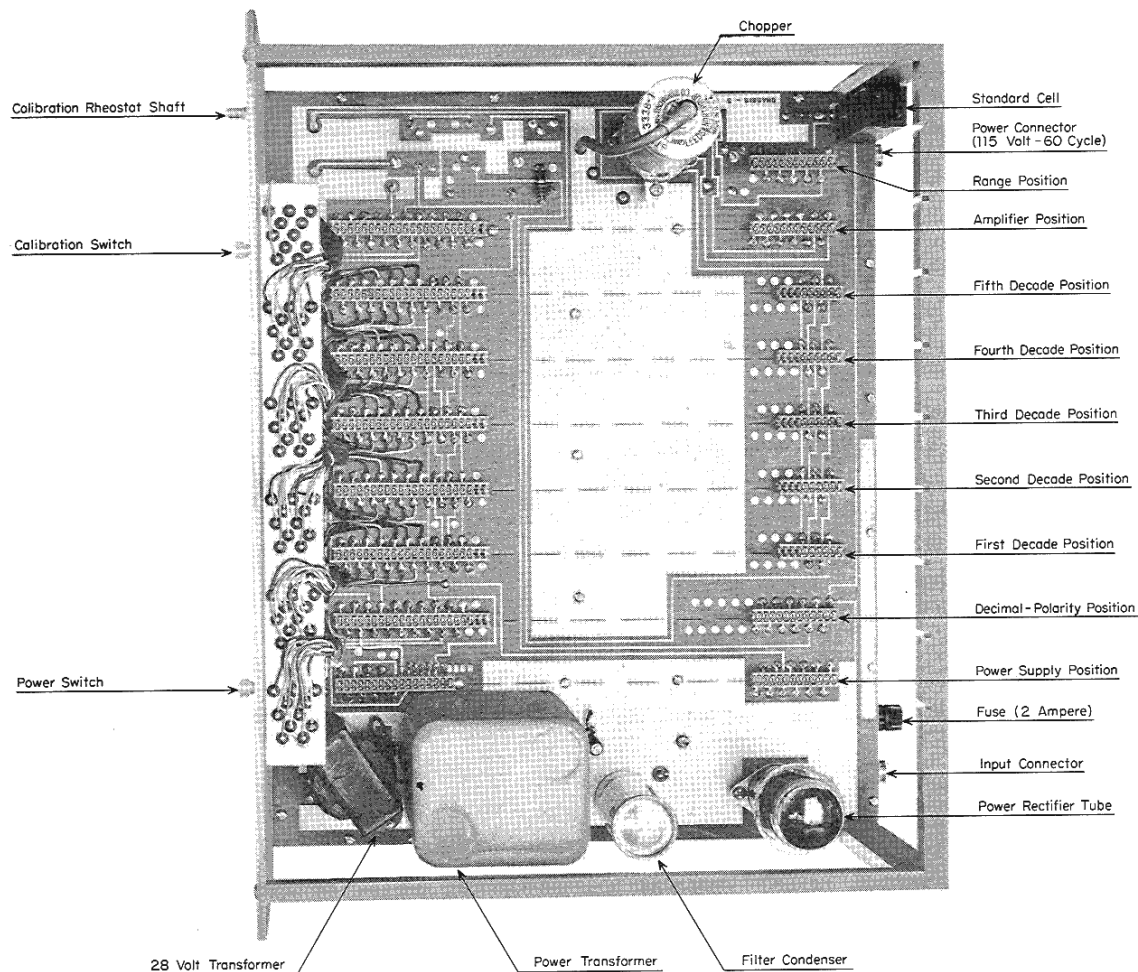
Typical Code No.		
PLUG-IN BOARD IDENTIFICATION	PS	15
	F	
PLUG-IN BOARD IDENTIFICATION	MATING CHASSIS PLUG LOCATION	NUMERICAL IDENTIFICATION OF CONTACT TABS
PS-Power Supply	F - Front	Count from Front to Rear
DP-Decimal Polarity	R - Rear	Count from Rear to Front
D1-First Decade	V - Vertical	Count from Top to Bottom
D2-Second Decade		
D3-Third Decade		
D4-Fourth Decade		
D5-Fifth Decade		
A-Amplifier		
R-Range		

## CIRCUITRY

For a general understanding of the electrical circuits incorporated in the digital voltmeters, refer to the simplified diagram, Figure 4. A detailed explanation of circuit operation will be found in the third section titled "Theory of Operation", page 21.

These digital voltmeters employ a comparison circuit which automatically balances a known variable voltage in discrete steps to equal an unknown input voltage. Visual readout is accomplished through continuous correspondence of a numerical indicator to the state of a high speed sequential relay circuit controlling the magnitude of the known feedback voltage. Each digital voltmeter is supplied with a standard cell which may be switched into the input for instant verification of the calibration.

**Figure 1 Top Chassis View**





# SECTION 1 ————— DESCRIPTION

**Figure 2 Bottom Chassis View**

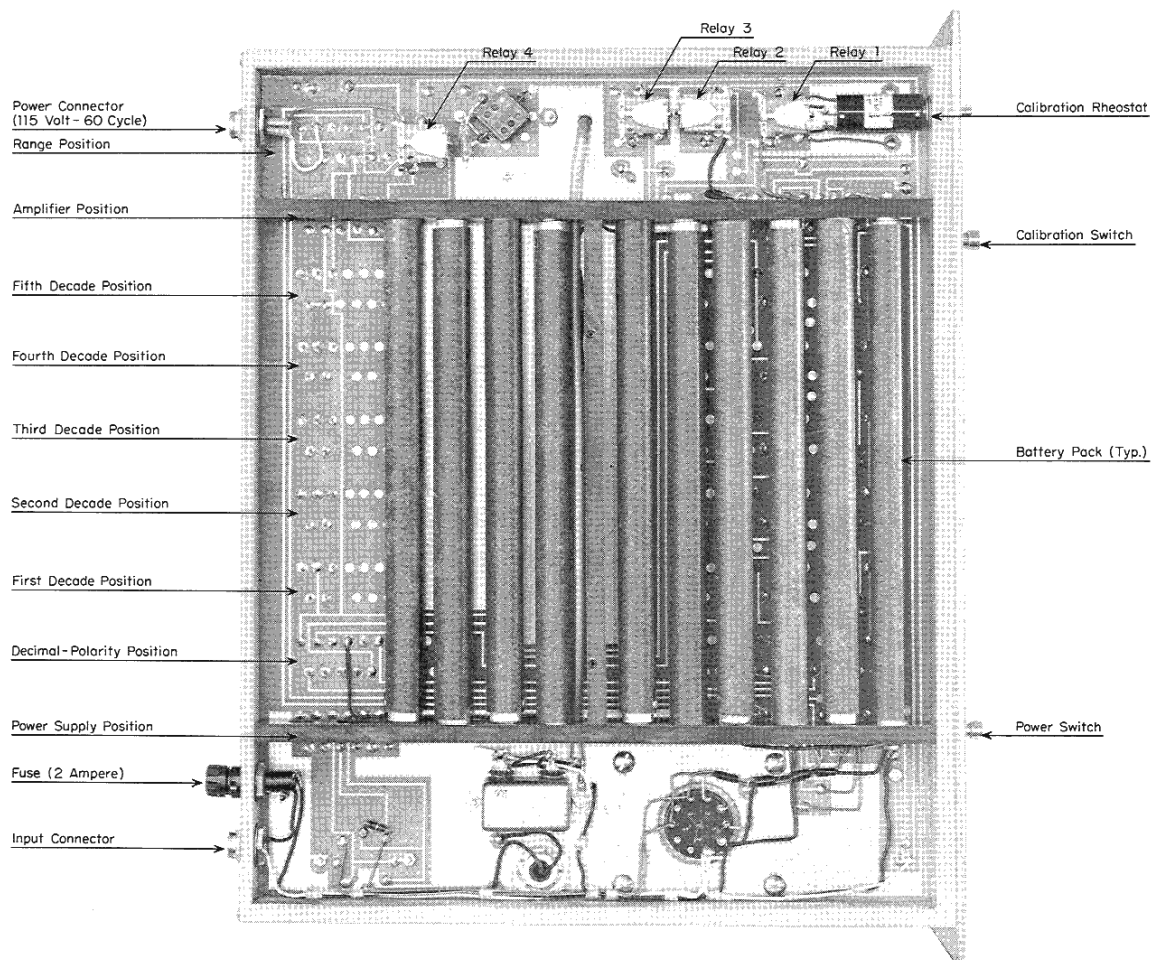


Figure 3 Standard Cell Certificate

I-142-B

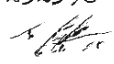
**MUIRHEAD**  
**D-550-A MINIATURE STANDARD CELL**

VOLTAGE *The e.m.f. of this cell has been measured and found to be within  $\pm 0.01\%$  of 1.01859 V abs. at 20°C. The e.m.f. at various temperatures is given in the following table:—*

Temp. °C	10	15	20	25	30	35	40
E.M.F. V abs.	1.01889	877	859	836	810	780	748

MAXIMUM CURRENT 10 $\mu$ A ; *for short periods*

INTERNAL RESISTANCE *Approximately 750 ohms at 20°C.*

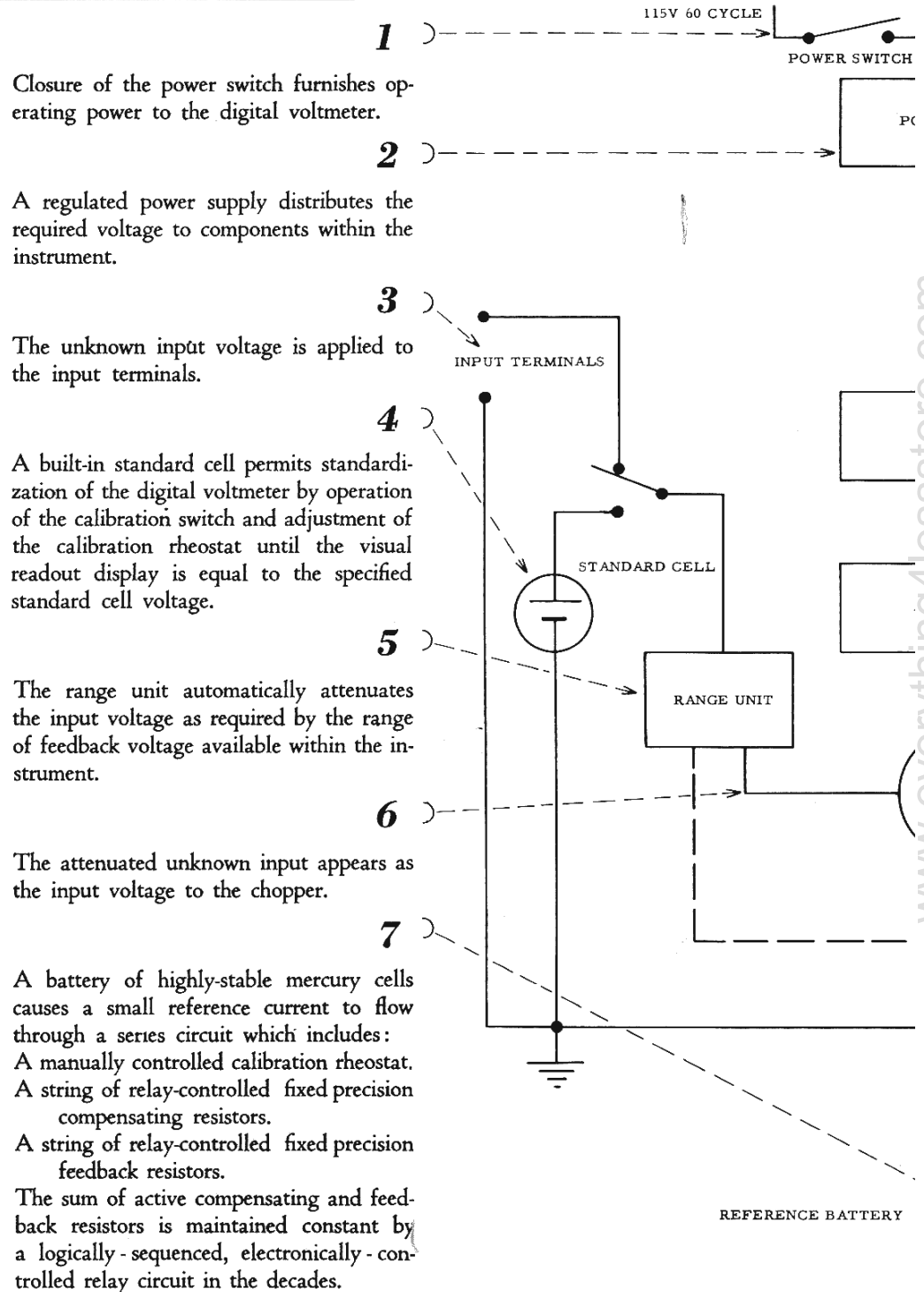
SERIAL No. 232398  
 TESTED BY   
 DATE 2.9.54.

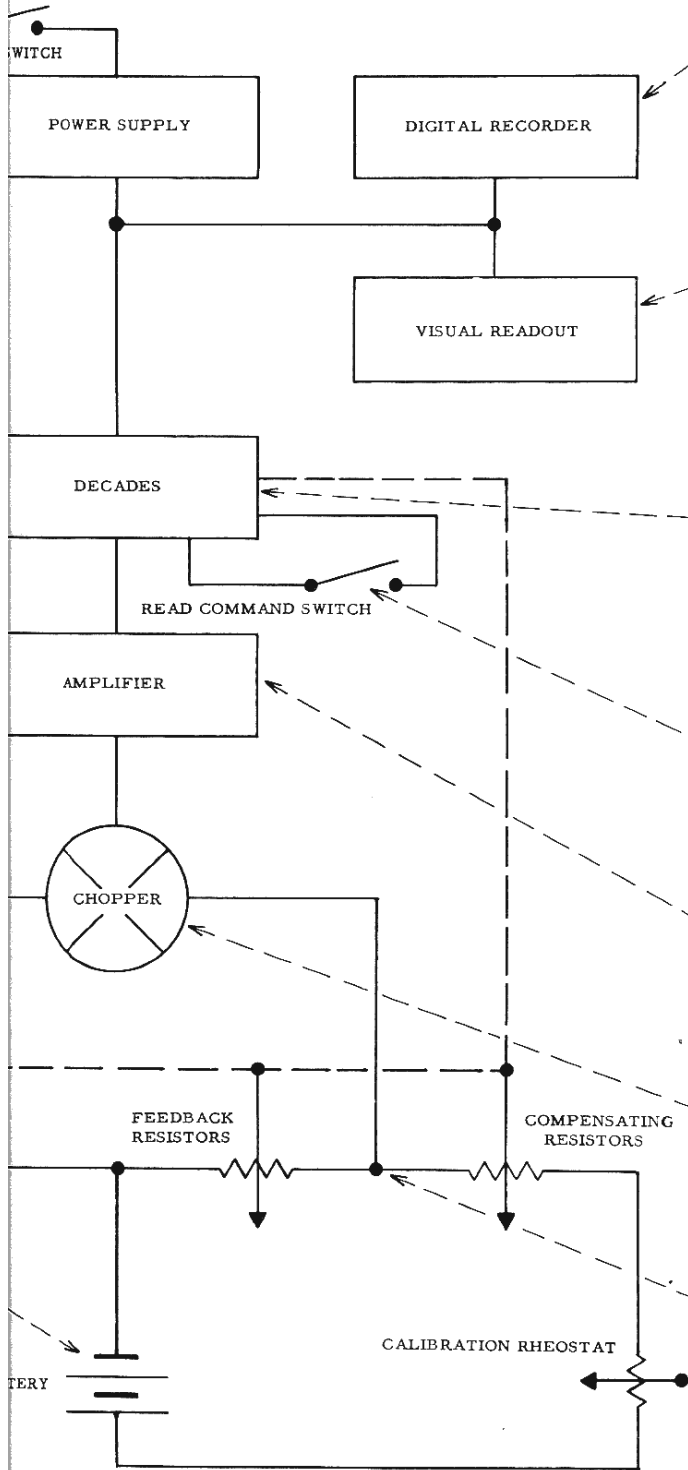
MOUNTING INSTRUCTIONS OVERLEAF

**MUIRHEAD & CO., LIMITED**  
 PRECISION ELECTRICAL INSTRUMENT MAKERS  
**BECKENHAM · KENT · ENGLAND**

Printed in England

**Figure 4 Simplified Block Diagram**





**14**

An accessory electric printer, typewriter or card punch automatically records the same measurement as that displayed in the visual readout.

**13**

After the digital voltmeter reaches a balance, it automatically deactivates itself and displays the polarity and magnitude of the unknown voltage at the visual readout.

**12**

The decade counting circuits automatically add or subtract increments of compensating and feedback resistance until the error signal becomes zero.

**11**

Momentary closure of the read command switch activates the instrument.

**10**

The amplifier emits "up" or "down" pulses to electronic counters in the decades.

**9**

The chopper sends an error signal to the amplifier.

**8**

A feedback voltage developed across the active feedback resistors by the flow of current from the reference battery is applied to the chopper.

SECTION 1 \_\_\_\_\_ DESCRIPTION

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## SECTION 2 ————— OPERATION

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### INSPECTION

The digital voltmeter is shipped with all plug-in components in place and ready to operate. However, upon receipt a thorough inspection for displacement or breakage should be made. Any damage resulting from shipment should be described on the Damage Report enclosed in the envelope at the back of this manual. The report should then be processed promptly according to the instructions thereon.

### INSTALLATION

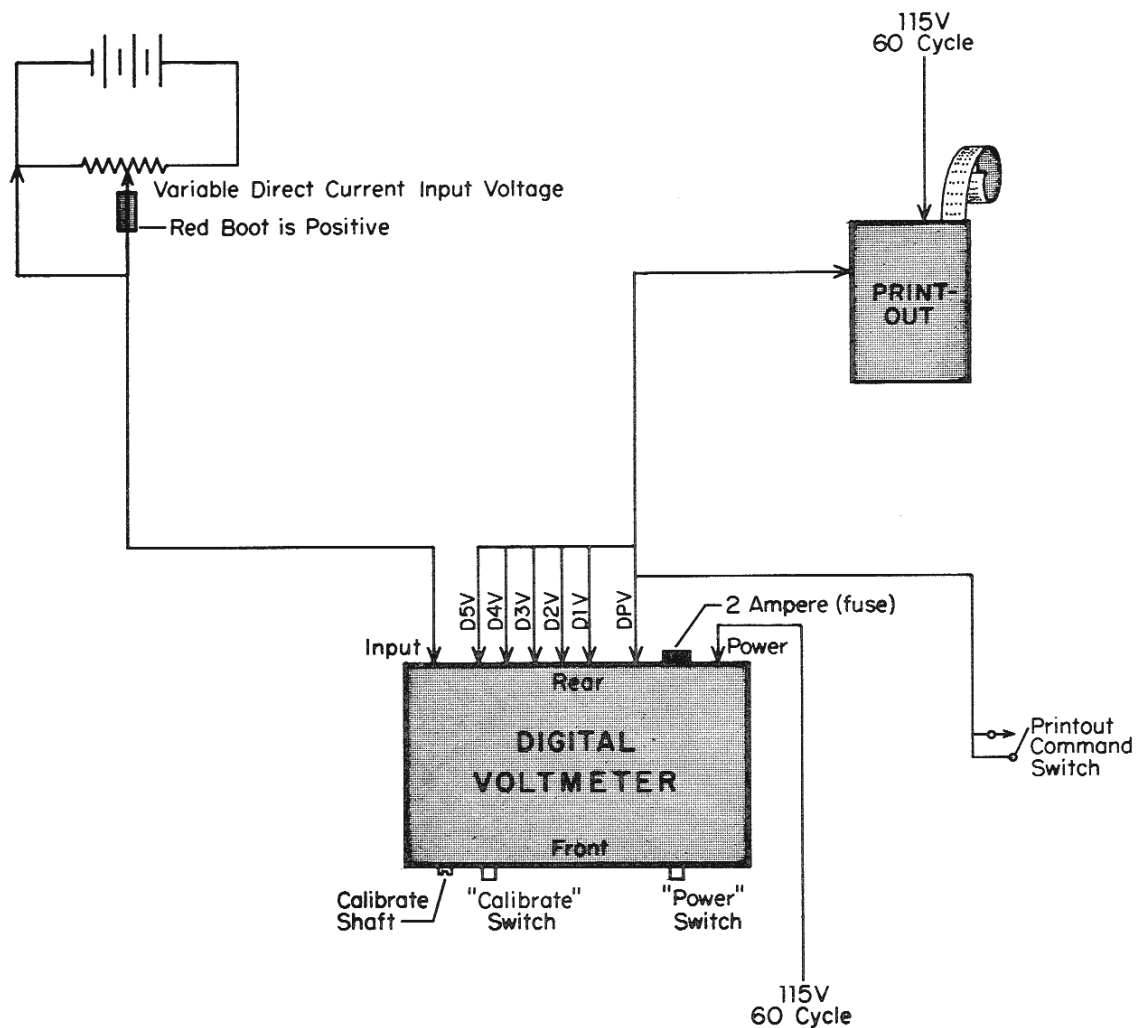
The digital voltmeter is designed for bench-top or rack-mounting installation. In either case, it should be placed for most convenient viewing of the visual readout. The sensitivity and high input impedance of the instrument makes it desirable to use short shielded leads for the direct current input voltage to avoid stray pickup. Although adequate shielding has been provided in the design of the instrument, operation in strong fields such as are found near transmitters and other high voltage sources may introduce spurious changes in readout indication.

Electrostatic pickup may be minimized by use of shielded input lines and with a good electrical ground on the chassis of the instrument. Sometimes reinserting the 115 volt alternating current power plug into the outlet receptacle in a position rotated 180 degrees from its previous position is helpful in reducing effects of stray pickup. Refer to Figure 5 on page 16 for diagram of connections to be used during bench check.

For actual installation, the variable direct current input supply consisting of the battery and voltage dividing potentiometer

shown in Figure 5 will be replaced by the lines whose voltage is to be measured. In some instruments, the negative side of the direct current input line is grounded to the etched circuit ground plane or the chassis board, which in turn is directly connected to the chassis frame. In cases where one side of the unknown voltage line to be measured is grounded internally in the equipment being tested, extreme caution should be exercised to connect the negative-grounded lead of the digital voltmeter to the negative-grounded lead of the circuit under test. The digital voltmeter is designed to operate from a 60 cycle 115  $\pm$  10-volt alternating current line. Excessive variation in line voltage may cause erratic operation of the instrument.

**Figure 5 Connection Diagram**



## STARTING THE INSTRUMENT

After making the connections to the digital voltmeter as shown in Figure 5, momentarily depress the "Power" switch on the right hand side of the front panel. Observe a "5" indication in each digit's place of the readout.

Digital voltmeters provided with means for making a printed record of the voltage measurement are disabled until the print command switch is closed. After approximately 30 seconds warm-up time, sustained closure of the print command switch will enable the instrument to change its readout indication to equal the numerical value of the voltage connected to the input terminals. As long as the print-command switch remains closed, the readout indication will follow any change in the input voltage. If the Model 519-P digital voltmeter is to be used for continuous visual indication of the input voltage, the print-command switch must be held closed. Opening of the print command switch will cause a printed record of the visual readout indication to be made as soon as the instrument reaches a balance.

## CALIBRATION

The Model 519-P digital voltmeter is calibrated before use by following the simple procedure outlined below. When models not supplied with printers are being calibrated, references to the print command switch are not applicable.

Allow approximately 30 seconds warm-up time after closure of the "Power" switch.

Maintain sustained closure of the print command switch to activate the digital voltmeter.

Momentarily depress the "1.018V" switch on the left side of the front panel.

Turn the slotted calibration rheostat shaft (located in the lower left-hand corner of the front panel) in a clockwise or counter-clockwise direction as required to obtain a visual readout display of "01.018".

Release the print command switch. A printed record of the calibration voltage (01.018 volts) will be made by the printer.

Momentarily depress the "1.018V" switch. In "P" series models, the readout indication will not change from "01.018"; but the instrument is now ready to measure, to display in visual readout form, and to make a printed record of the voltage on the input lines.

### MAKING DIRECT CURRENT VOLTAGE MEASUREMENTS

To make a voltage measurement after calibration has been accomplished, it is necessary only to close momentarily the print command switch. The visual readout indicator will display the numerical value and polarity of the voltage applied to the direct current input leads. As soon as the visual readout indication becomes stabilized, the printer automatically makes a printed record of the visual readout indication.

### ADJUSTMENTS

Adjustments of the gain and hum controls are described on page 63, "Maintenance". These are the only adjustments needed other than calibrating the instrument periodically to compensate for temperature effects on the standard cell and reference battery circuit.

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## SECTION 3 ————— THEORY OF OPERATION

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## GENERAL

In the following discussion of operational theory, it is suggested that the following diagrams be consulted:

Figure 4	Simplified Diagram	Page 11
Figure 12	Functional Block Diagram	Page 77
Figure 13	Wiring Diagram	Page 77

## POWER SUPPLY CIRCUITS

The power supply circuits provide unregulated alternating current of 350, 115, 24 and 6.3 volts, and 24 volts direct current to various points in the digital voltmeter. Regulated power supply voltages are +250, +150 and -150 volts direct current. For convenience in packaging, some of the power supply components are mounted on the power supply board, whereas others are mounted on the top right hand side of the chassis board.

The filaments of the amplifier tubes and power supply tubes are supplied with 6.3 volts alternating current from the power transformer. Decade 1 and the decimal-polarity boards receive filament supply at 28 volts from the 115 to 28 volt transformer. This transformer also supplies alternating current power to the full wave rectifier for operation of the buffer relays, decade transfer relays and readout lamps. The filaments of decades 2 thru 5 are in series with a 50 ohm, 10 watt dropping resistor across the 115 volt alternating current line. In the Model 300 series, an 84 ohm resistor replaces the filaments of the second decade.

## VOLTAGE MEASURING AND READOUT CIRCUITS

### ----REQUIREMENTS

In order to determine the magnitude of an unknown direct current voltage, the digital voltmeter must be capable of performing the following functions rapidly and accurately:

Sample the unknown direct current input voltage at closely spaced time intervals.

## SECTION 3 ————— THEORY OF OPERATION

Sample the feedback voltage synthesized within the digital voltmeter at the same rate as above.

Supply information to the amplifier pertaining to the magnitude and sense of the difference, or error voltage, between the two samples mentioned above.

Upon receipt of the error signal, the amplifier must send to the decades "up" or "down" pulses which will raise or lower the voltage developed across the series of feedback voltage resistors until this voltage, and the error signal, becomes either zero or less than the resolution of the digital voltmeter.

Display in numerical form the absolute magnitude of the synthesized feedback voltage which equals the unknown applied voltage.

### -----DESCRIPTION

The following paragraphs describe the major characteristics of the various individual circuits.

#### -----Unknown Input Circuit

In Model 519-P and other models employing automatic or manual decimal shift, the normally positive unknown input line is connected to the top of a voltage divider network located on the range unit. Reference to Figure 13 shows continuity from pin 1 on the direct current voltage input receptacle to the top of the voltage divider through the normally closed calibration relay contacts (chassis relay 4) and pin RR1.

The negative direct current input voltage line is grounded within the digital voltmeter. The bottom end of the range unit voltage divider is connected to ground through pin RR3.

Automatic range switching and consequent shift in decimal point location in the visual readout is accomplished by selective control of range unit relays 15 and 16. This control is effected on the decimal-polarity board and is described in detail on page 45 (Automatic Decimal Shift and Ranging Circuits).

The unknown direct current voltage, selected from the range

unit attenuating resistor by relays 15 and 16, and is applied to pin 4 of the chopper through pin RR2 and a 100,000 ohm resistor.

#### -----Feedback Voltage Circuit

A voltage is developed within the digital voltmeter as a voltage drop across a series of fixed precision feedback resistors. The magnitude of the feedback voltage is automatically raised or lowered until it equals the unknown input voltage. Reference to Figures 12 and 13 shows that the feedback voltage circuit is composed of the following elements connected in series across a battery of highly stable mercury cells:

- a. Chassis RY1 contacts used in automatic or manual polarity indication.
- b. Calibrating rheostat (shaft accessible through lower left corner of front panel).
- c. A series circuit of four fixed precision compensating resistors mounted on each plug-in decade board. The ohmic values of these compensating resistors in the first decade (extreme right hand location) are 1 ohm, 2 ohms, 4 ohms, and 8 ohms, constituting a binary system. Ohmic values of the compensating resistors in the 2nd, 3rd, 4th, and 5th decades are respectively 10, 100, 1000, and 10,000 times the ohmic values of the compensating resistors in the first decade.

In the digital voltmeter, the compensating resistors of one decade are connected in series with the compensating resistors on all other decades. Each compensating resistor (on whatever decade) is shunted by a set of normally-open compensating relay contacts identified by the numbers 11, 21, 41, or 81. Closure of any one set of compensating relay contacts reduces the total compensating-string resistance in the instrument by the ohmic value of the resistor associated with the particular set of compensating relay contacts that are closed. Coils of the compensating relays are in series with plate circuits of the pulse counter tubes described in detail on page 26, "Pulse Counting Circuit".

- d. A series circuit of four fixed precision feedback resistors also are mounted on each decade board. (The above remarks about compensating resistors apply to the feedback resistor circuits as well, except that feedback relays are identified by the numbers 10, 20, 40, or 80. The feedback resistor circuit is grounded between pin D1R3 and the armature of RY3 on the chassis. It should also be noted that the junction of the compensating and feedback resistor strings at D5R4 and D5R2 is connected to pin 2 of the chopper. Thus, the feedback voltage (which is compared to the unknown input voltage) is developed between pin 2 of the chopper and ground.
- e. Chassis RY3 contacts are provided to open the reference battery circuit when the digital voltmeter is not in use.
- f. Chassis RY2 contacts are used in automatic or manual polarity indication.

#### -----Error Signal

The chopper driving coil is connected through a phase-shifting network to the 60-cycle line voltage. Thus the chopper samples the unknown input voltage at pin 4 and the feedback voltage at pin 2 at a rate of 120 samplings per second. If the unknown input voltage and the feedback voltage are not equal to each other, a square wave type error signal is conducted from pin 3 of the chopper to the amplifier input.

#### -----Amplifier

The amplifier receives the error signal from the chopper, amplifies it, compares its phase with that of the 350 volt 60 cycle voltage at the plates of the 5696 thyratrons, and sends out either "up" pulses from AF7 or "down" pulses from AF8. The pulses go to the pulse-counting circuit on the first decade through the contacts of RY17 and RY18 on the decimal polarity board. These relays are energized only when a negative polarity sign is indicated in the visual readout, as described on page 40, "Automatic Polarity Indication Circuits".

-----Pulse Counting Circuit

The pulse counting circuit of the first decade is identical to that of all the other decades. It consists of four 5963 twin triodes connected as a pulse-dividing counter.

Table III and Figure 13 identify the decade circuits which contain: (1) compensating relay coils; (2) feedback relay coils; and (3) binary to decimal conversion relay coils for visual readout display.

Table III Identification of Relay Coils Connected in Plate Circuits of Each Decade Pulse Dividing Counter.

RELAYS	FIRST PLATE SECTION (P1)				SECOND PLATE SECTION (P2)			
	V1	V2	V3	V4	V1	V2	V3	V4
FEEDBACK RELAY NO.	10	20	40	80	None	None	None	None
COMPENSATING RELAY NO.	None	None	None	None	11	21	41	81
BINARY TO DECIMAL CONVERSION RELAYS	10A	20A	40A	80A	11A	21A	None	81A
	10B				11B			

The counter circuits are arranged in such a manner that the first or second plate circuit of any one counter tube is always conducting, but both plate circuits never conduct simultaneously.

Table IV identifies the decade relays which are energized or de-energized when displaying a particular digit in the readout window associated with that decade.



# SECTION 3 ————— THEORY OF OPERATION

Table IV Decade Relay Locations and States of Energization or De-energization for Each Associated Readout Digit.

DECADE RELAYS & ASSOCIATED PULSE-COUNTER PLATE CIRCUITS									
TO B+ 250 VDC									
DIGIT*	P1	P2	P1	P2	P1	P2	P1	P2	P2
0	1	0	1	0	1	0	1	0	0
1	0	1	1	0	1	0	1	0	0
2	1	0	0	1	1	0	1	0	0
3	0	1	0	1	1	0	1	0	0
4	1	0	1	0	0	1	1	0	0
5	0	1	1	0	0	1	1	0	0
6	1	0	0	1	0	1	1	0	0
7	0	1	0	1	0	1	1	0	0
8	1	0	1	0	1	0	0	1	1
9	0	1	1	0	1	0	0	1	1

## NOTE:

- 1 Signifies Plate Circuit Conducting, Relays Energized.
- 0 Signifies Plate Circuit Not Conducting, Relays De-energized.
- \* Digit Displayed in Associated Readout Window.

"Up" pulses are applied to the counter circuits of the first decade from pin D1F18 through a set of normally closed "9" relay contacts. Transfer of "up" pulses to the next decade is affected by operation of the "9" relay whose operating coil is in parallel with the "9" indicator lamp in the associated visual readout window.

"Down" pulses arriving at pin D1F15 on the first decade are coupled to the number 1 grid of each counter tube through a set of normally closed "0" relay contacts and an NE2 neon bulb. Transfer of "down" pulses to the next decade is effected by operation of the decade "0" relay whose operating coil is in parallel with the "0" indicator lamp in the associated visual readout window.

## -----Visual Readout

The visual readout device was developed by Non-Linear Systems, Inc., for simple, rapid, and effective display of voltages measured by the digital voltmeter. The readout consists of transparent lucite plates upon which are engraved the characters to be displayed. Each plate is individually and selectively edge-lighted by a small 28-volt lamp, causing the characters engraved on the plate to appear as a thin, bright, sharply defined line against a dark background. Selective lighting of the lucite plates is accomplished automatically by supplying 28 volt direct current to the readout lamps through the logically sequenced binary-to-decimal conversion relays mounted on the decades. Electrical connections of these relays to the readout lamps are shown in the decade 1 block of Figure 13 and are identical in all other decades. Digital voltmeters designed for recording operation also carry a series of buffer relays on each plug-in board. These relays and their functions are discussed in detail on page 56, "Recording Circuits".

## -----Calibration Circuit

In general, the absolute value of the balance voltage developed across the total active balancing resistors will not agree with the visual readout indication until the digital voltmeter is calibrated against a known voltage. Calibration is accomplished as described on page 39, "Calibration". Components involved in the calibration of instrument are the:

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- a. "1.018V" switch
- b. Chassis Relay 4
- c. Miniature certified standard cell
- d. Calibrate rheostat in series with the reference battery and the precision compensating and feedback voltage resistor strings.

Detailed functional description of the calibration circuit components is described on page 37.

### -----FUNCTIONAL OPERATION

#### -----General

In the functional description of the voltage measuring and visual display circuits, it is assumed that the Model 519-P digital voltmeter is connected as shown in Figure 5. In addition, the print-command switch is maintained closed to enable the visual readout to indicate continuously the magnitude of the unknown input voltage. As long as the print-command switch remains closed, the recording device is held inoperative and will not print the numerical value of the measured voltage. Detailed functioning of the recording circuits is described on page 56, "Recording Circuits". It is further assumed that the voltage to be applied to the digital voltmeter is positive, and is in the range from 00.000 to 99.999 volts. Detailed functional description of the automatic polarity and decimal shift circuits appears on page 40, "Automatic Polarity Indication Circuits", and page 45, "Automatic Decimal Shift and Ranging Circuits".

#### -----Initial Conditions

Operation of the "Power" switch to the ON position applies 115 volts alternating current to the primary of the 115-28 volt step-down transformer. The secondary of this transformer supplies 28 volts alternating current to the full-wave dry-plate rectifier resulting in 28 volts direct current becoming immediately available at terminals PSR8 and PSF15. Terminal PSR8 is grounded at the visual readout, while chassis printed circuit lines conduct positive 28 volt direct current from PSF15 to pin F14 at each decade position, and to DPF15 on the decimal-polarity

board.

Since the decade decoding relays are not yet powered, due to absence of B+ voltage at the counter tubes, positive 28 volt direct current is conducted from the F14 terminal of each decade to the associated readout "5" lamp through the normally-closed contacts of relays 40A, 21A, and 10B. Likewise, the readout "+" lamp is energized through the normally closed decimal-polarity relay 12, and the decimal #2 lamp is energized through the normally closed contacts of decimal-polarity relays 13 and 14. Immediately after operation of the "Power" switch to the ON position, the visual readout will indicate a "+555.55" regardless of the magnitude or polarity of the unknown voltage applied to the input leads of the instrument. In P-series models, the 105 buffer relays are also energized at this time because their coils are in parallel with the "5" readout lamps. As indicated above, recorder operation is described on page 56, so no further consideration of buffer relay circuit operation will be made at this point.

"Power" switch closure also instantly energizes the chopper coil. Further, closure of the "Power" switch applies 115 volts alternating current to the filaments of the counter tubes in decades 2, 3, 4, and 5 in series with a 50-ohm 10 watt resistor. The 28 volt alternating current line powers the series decade 1 filaments in parallel with the series decimal-polarity filaments. Amplifier filaments are all connected in parallel across the 6.3 volt alternating current winding of the power transformer terminals 6 and 8, as well as the 12AX7 and 6AS7G filaments in the power supply. In addition, closure of the "Power" switch makes 350 volts alternating current available from the power transformer terminal 5 to AF10 for plate voltage to the two 5696 thyratrons in the amplifier.

Approximately 30 seconds after operation of the "Power" switch to the ON position, filament temperatures in the power supply have increased to the point where 250 volts direct current, +150 volts direct current and -150 volts direct current is available at the PSF6, PSF11, and PSF10 terminals, respectively, for distribution to various points in the instrument as indicated in Figure 13. The digital voltmeter will now display the polarity and magnitude of the unknown voltage applied to the input leads. Whenever the Model 519-P voltmeter indicates a positive voltage in the range from 00.000 to 99.999, various relays on the

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chassis, range unit and decimal-polarity board are in the energized or de-energized states shown in Table V.

**Table V** Location and Function of Relays Which Do Not Change Their States When Making Measurements in the Range from 00.000 to 99.999.

RELAY LOCATION	RELAY NO.	RELAY STATE	RELAY CONTACT FUNCTION IN SHOWN STATE
Chassis	1&2	Energized	Selects proper reference battery polarity to indicate a positive voltage at readout.
	3	Energized	Connects reference battery to compensating and balance resistor circuits only after "Power" switch is operated to ON position.
	4	Not Energized	Connects unknown input voltage to input end of ranging resistor.
Range Unit	15	Energized	Connects unknown input voltage from input end of ranging resistor to chopper pin 4 through normally closed relay 16 contacts and 100,000 ohm resistor.
	16	Not Energized	
Decimal-Polarity Board	13	Energized	Lights extreme left (decimal#1) lamp in visual readout.
	12	Not Energized	Lights "+" lamp in visual readout.
	17	Not Energized	Connects amplifier "up" pulse line (AF7) to 1st decade "up" pulse line (D1F18).
	18	Not Energized	Connects amplifier "down" pulse line (AF8) to 1st decade "down" pulse line (D1F15).
	1	Energized	Disconnects amplifier thyatron cathodes from ground in decimal-polarity board to enable the digital voltmeter immediately to change its visual readout to correspond to the magnitude of the unknown input voltage.

**Table VI** Compensating and Feedback Resistances for Particular Visual Readout Indications.

VISUAL READOUT DISPLAY	PRECISION RESISTORS	O H M S					
		DECADE NUMBER					TOTAL OF FIVE DECADES
		5	4	3	2	1	
00.000	Compensating	150,000	15,000	1,500	150	15	166,665
	Feedback	0	0	0	0	0	0
	Total	150,000	15,000	1,500	150	15	166,665
00.001	Compensating	150,000	15,000	1,500	150	14	166,664
	Feedback	0	0	0	0	1	1
	Total	150,000	15,000	1,500	150	15	166,665
00.903	Compensating	150,000	15,000	600	150	12	165,762
	Feedback	0	0	900	0	3	903
	Total	150,000	15,000	1,500	150	15	166,665
01.018	Compensating	150,000	14,000	1,500	140	7	165,647
	Feedback	0	1,000	0	10	8	1,018
	Total	150,000	15,000	1,500	150	15	166,665
99.999	Compensating	60,000	6,000	600	60	6	66,666
	Feedback	90,000	9,000	900	90	9	99,999
	Total	150,000	15,000	1,500	150	15	166,665

## -----Automatic Feedback Voltage Synthesis

When the visual readout indicates 00.000 volts, all of the feedback relays in each decade are energized and their contacts short circuit the associated precision feedback resistors. In this condition, a resistance of zero ohms is developed between the grounded pin D1R3 and the chopper pin 2. At the same time all of the compensating relays are de-energized, resulting in 166,665 ohms in the compensating resistor string between pin D1R1 and chopper pin 2. Table IV indicates that when a feedback relay in any decade is energized, its associated compensating relay is de-energized. Thus, the sum of the active resistors in the compensating and feedback resistor strings is always constant at 166,665 ohms, regardless of the readout indication. Table VI shows the amount of active resistance in the computing and feedback resistor strings in each decade, and in the total circuit for various readout indications.

It is easy to see that if the calibration rheostat is adjusted to permit one milliamperere to flow through the constant 166,665 ohm sum of the compensating and feedback resistors in series, each ohm of resistance will develop a drop of one millivolt.

Let it be assumed that the amplifier gain is set at one millivolt, the current through the compensating and balance circuit is equal to one milliamperere, and the visual readout display is 00.000 volts. Let the unknown input voltage be increased to 00.001 volts. The chopper samples the 1 millivolt input voltage and the zero balance voltage developed between D5R4 and D1R3 (ground). The resulting one millivolt error signal is sent to the amplifier, which in turn sends out an "up" pulse to the first decade. This "up" pulse is coupled to both grids of the first counter tube (V1) through a 50 micromicrofarad condenser. The positive "up" pulse at grid 1 (pin 7) of V1 has no effect on the conduction of the first section of V1. The same "up" pulse appearing at grid 2 (pin 2) of V1, however, biases the second section of V1 to conduction. As a result of this conduction the plate voltage at pin 1 of V1 decreases and biases the first section of V1 to cut-off.

When section 1 of V1 stops conducting, the plate voltage at pin 6 rises and maintains grid 2 at conducting potential even after the original "up" pulse has disappeared. This shift in conduct-

ion from the first section to the second section of V1 is shown in Table IV. Extinction of section 1 of V1 de-energizes the three 10-series relays while the newly established conduction of section 2 of V1 energizes the three 11-series relays. De-energization of relay 10 causes its contacts to unshort the 1 ohm feedback resistor in the first decade. Since the current through the compensating and feedback circuits is constant at 1 milliamperes the change in feedback string resistance from zero to 1 ohm results in the development of 1 millivolt drop between the chopper pin 2 and ground. Energization of relay 11 causes its contacts to short circuit the 1 ohm compensating resistor in the first decade. This condition is shown in Table VI for the visual readout indication of 00.001.

We note further that when the visual readout indication showed a "0" in the 1st decade position, the "0" readout lamp was energized by 28 volts direct current through:

- a. Closed normally-open 40A relay contacts.
- b. Closed normally-open 20A relay contacts.
- c. Normally closed 11B relay contacts.
- d. Closed normally-open 80A relay contacts.

After the shift in conduction from the 1st to the 2nd section of V1 (which resulted from one "up" pulse entering the 1st decade), relay 11B closes its normally open contacts to energize the 1st decade "1" readout lamp. The visual readout display now shows "+00.001". Because the chopper coil is continuously energized from the 60 cycle line, the chopper continues sampling the input voltage and the synthesized feedback voltage. These voltages are now equal to each other and no error signal is sent to the amplifier. Thus, no additional "up" or "down" pulses are sent out from the amplifier to the decades, and the digital voltmeter is said to have reached a condition of balance. This balanced condition will be maintained indefinitely unless the input or synthesized balance voltages change by at least one millivolt.

If the unknown input voltage is increased from 00.001 to 00.002 volts, a second "up" pulse appears at the first decade pin D1F18.



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This second pulse restores V1 to its original or "zero" conduction state with the consequent de-energization of the 11-series relays and energization of the 10-series relays. When the second section of V1 stops conducting, the plate voltage at pin 1 of V1 rises to maintain conduction of the first section of V1. The rise in voltage at pin 1 of V1 appears at pin 2 of V2 as a positive pulse, biasing section 2 of V2 to conduction and energizing the 21-series relays. At the same time, section 1 of V2 stops conduction and de-energizes the 20-series relays. The action of V1 and V2, upon receipt of a second "up" pulse at the first decade, operates to:

- a. Remove one ohm from the feedback resistance string.
- b. Insert one ohm in the compensating resistance string.
- c. Extinguish the first decade "1" readout lamp.
- d. Remove 2 ohms from the compensating resistance string.
- e. Insert 2 ohms to the feedback resistance string.
- f. Energize the first decade "2" readout lamp.

As a result of changing the input voltage from 00.001 to 00.002 volts, the visual readout display changes from "+00.001" to the "+00.002", again establishing an equality of the input and balance voltages. This equality results in a zero error signal which precludes further amplifier pulse output as long as this equality is maintained.

In the preceding discussion it should be noted that the second, third, fourth, and fifth decades are unaffected by pulses arriving at the first decade because they are isolated from the first decade input pulse lines by the normally open "9" and "0" relay contacts of the first decade.

Now consider the circuit actions when the input voltage is changed from 00.009 to 00.010 volts. When the visual readout indicates "+00.009", the relays in the counter tube plate circuits of the first decade are in the states shown in Table IV for the "9"-digit readout display. In addition, the first decade "9"

transfer relay is now energized because the coil of the "9" relay is in parallel with the first decade "9" readout lamp. Energization of the "9" transfer relay disconnects the first decade counter circuit from the "up" pulse line at D1F18. Likewise upon energization of the "9" transfer relay, closure of the normally open "9" relay contacts connects the counter circuit of the second decade to the "up" pulse line at D1F18.

If the input voltage is now increased from 00.009 to 00.010 volts, the resulting "up" pulse bypasses the first decade counting circuit and enters the second decade counting circuit. The second decade counter tube plate circuit relays now assume the state shown in Table IV for the "1" digit readout display. This means that 10 ohms have been inserted in the second decade feedback resistor string while the first decade maintains 9 ohms in its balance resistor circuit. Since the second decade compensating relay simultaneously acts to remove 10 ohms from the second decade compensating resistance circuit, the sum of all active compensating and feedback resistors in series between D1R1 and D1R3 remains constant at 166,665 ohms and the current through this circuit remains constant at 1 milliamperes. We now have 19 millivolts (10 millivolts in 2nd decade plus 9 millivolts in 1st decade) of feedback voltage drop developed from the chopper pin 2 to D1R3. This feedback voltage is greater than the input voltage, and the resulting error signal at the amplifier input is 180 degrees out of phase with the error signal which results when the feedback voltage is smaller than the input voltage. The amplifier senses this 180 degree phase shift in error signal and now sends out a "down" pulse from AF8, through the normally closed relay "18" contacts of the decimal polarity board to the first decade at pin D1F15.

The second decade is unaffected by the "down" pulse because it is isolated from the "down" pulse line by the normally open contacts of the first decade "0" transfer relay. The "down" pulse appearing at D1F15 is applied to the 1st section grids (pin #7) of all four counter tubes in the first decade through the normally closed "0" transfer relay contacts and four parallel NE2 neon lamps. Application of the "down" pulse to the first section grids of all counter tubes in the first decade biases these tube sections to conduction resulting in first decade relay states shown in Table IV for the "0" digit readout display. The balance voltage now sampled by the chopper is 10 millivolts

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(10 millivolts in 2nd decade plus 0 millivolts in 1st decade), which is equal to the input voltage. Since the error signal is now zero, no further pulses appear at the amplifier output terminals and the digital voltmeter is again said to be balanced with a visual readout display of "+00.010" volts. Note that the "0" transfer relay in each decade is in parallel with the "0" readout lamp associated with that decade. Thus, when the readout display is "+00.010" volts, the first decade counter circuit is isolated from the "down" pulse line (D1F15) by the opening of the normally closed "0" transfer relay contacts.

If the input voltage is decreased from 00.010 to 00.009 volts, the amplifier sends out a "down" pulse which bypasses the first decade counter circuit and is applied to the first section grids of all four counter tubes in the second decade through the normally closed second decade "0" transfer relay contacts. The counter tube plate circuits in the second decade assume the states shown in Table IV for the "0" digit readout display. In this condition the momentary total readout display is "+00.000", which indicates that the feedback voltage is momentarily zero. However, the input voltage is still 00.009 volts. The resulting 9 millivolt error signal causes the amplifier to emit an "up" pulse changing the readout indication and feedback voltage to "+00.001". An 8 millivolt error signal causes the amplifier to emit another "up" pulse which in turn changes the readout indication and balance voltage to "+00.002". This process continues until the error signal has decreased to zero in 1 millivolt steps and the visual readout indicates "+00.009" volts as shown in Table VII. The entire change in readout display from "+00.010" to "+00.009" is accomplished in 10/60 seconds.

**Table VII** Transient Readout Display and Associated Error Signal Magnitude When Input Voltage Changes from 00.010 to 00.009 Volts.

INPUT VOLTS	READOUT DISPLAY & FEEDBACK VOLTS	MV ERROR SIGNAL	AMPLIFIER OUTPUT PULSE	REMARKS
+00.010	+00.010	0	None	Digital Voltmeter at Balance
+00.009	+00.010	-1	Down	Transition Period
+00.009	+00.000	+9	Up	
+00.009	+00.001	+8	Up	
+00.009	+00.002	+7	Up	
+00.009	+00.003	+6	Up	
+00.009	+00.004	+5	Up	
+00.009	+00.005	+4	Up	
+00.009	+00.006	+3	Up	
+00.009	+00.007	+2	Up	
+00.009	+00.008	+1	Up	
+00.009	+00.009	0	None	Digital Voltmeter at Balance

Note: "+"error signal indicates input voltage is greater than the feedback voltage.

"-"error signal indicates input voltage is less than the feedback voltage.

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The foregoing discussion presents the basis for analyzing in detail the action of the voltage measuring and visual readout display circuits for any change of input voltage.

### -----Calibration

A first momentary operation of the "1.018V" switch located in the lower left hand corner of the front panel closes the switch and maintains 250 volts direct current through a 68,000 ohm resistor to the coil of the calibration relay (chassis relay 4). Energization of the calibration relay coil opens the normally closed relay 4 contacts, disconnecting the unknown input voltage from the top of the range unit voltage divider. Consequent closure of the normally open relay 4 contacts connects a certified miniature standard cell to the top of the range unit voltage divider through a 4700 ohm resistor. The visual readout then should indicate "+01.018" volts after the "1.018V" switch is operated to the ON position. A second momentary operation of the "1.018V" switch opens the switch and de-energizes chassis relay 4.

A readout display greater than "01.018" indicates that the current through the compensating and feedback resistors is too low, while a readout display lower than "01.018" indicates that the feedback resistor current is too high. The visual readout display can be controlled by manually adjusting the calibration rheostat in series with the reference battery and the compensating and feedback resistor strings. Table VI indicates the portion of the total feedback string resistance contributed by each decade for a visual readout display of "01.018" volts. The feedback resistor current can be calculated as follows:

$$\frac{01.018 \text{ volts}}{1018 \text{ ohms}} = 0.001 \text{ amperes} = 1 \text{ milliampere}$$

This calculation explains the reason for the previous assumption (page 33) that the current through the feedback and compensating resistors is 1 milliampere.

## AUTOMATIC POLARITY INDICATION CIRCUITS

### ----REQUIREMENTS

When a voltage applied to terminal 1 of the input voltage receptacle (clip covered with a red boot) is positive with respect to terminal 2 of the receptacle (bare clip), the polarity sign prefixing the numerical readout display should show as "+". When the polarity of the applied voltage is reversed, the visual readout polarity sign should change to "-".

### ----DESCRIPTION

The components involved in the automatic polarity indication circuits are shown in Figure 13 and are listed below:

Chassis relays 1 and 2.

A 5963 electron tube (V5) and associated circuits on the decimal polarity board.

Decimal-polarity relays 17 and 18.

Transfer relay 0 in decades 1, 2, 3, and 4.

Relay 81A in decade 5.

Decimal-polarity relay 0.

Decimal-polarity relay 12.

Visual readout "+" indicator lamp.

Visual readout "-" indicator lamp.

### ----FUNCTIONAL OPERATION

#### -----Initial Conditions

Table VIII shows the state of the automatic polarity indication circuit components when a "+" sign is displayed in the visual readout.

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**Table VIII** State of Automatic Polarity Indication Circuit Components for a "+" Visual Readout.

ENERGIZED	NOT ENERGIZED	CONDITIONAL
Chassis Relay 1	Decimal Polarity Relay 17	Relay 0 in decades 1, 2, 3, and 4 are energized only when associated visual readout windows display "0".
Chassis Relay 2	Decimal Polarity Relay 18	Relay 81A in 5th decade is energized only when associated visual readout window displays "0".
Second Triode Section of V5	Decimal Polarity Relay 12	Relay 0 on decimal polarity board is energized only when the associated visual readout window displays "0".
"+" Visual Readout Lamp		

### -----Change of Readout Display from "+" to "-"

From the previous discussion of the voltage measuring circuits, we observe that the amplifier emits "up" pulses whenever the potential at chopper pin 4 is greater than the potential at chopper pin 2. Likewise, the amplifier emits "down" pulses whenever the potential at chopper pin 4 is less than the potential at chopper pin 2.

In order to examine in detail the various circuit functions involved in automatically changing the readout polarity display from "+" to "-", let us assume that the readout display is now at "+79.503". If the input voltage to the digital voltmeter is suddenly changed from +79.503 to -79.503 volts, the potential at the chopper pin 4 becomes negative (or less than the potential at chopper pin 2) resulting in "down" pulses appearing at D1F15.

The first "down" pulse enters the first decade counting circuit and momentarily changes the readout display to "+79.500" at which time the first decade relay 0 is energized, permitting subsequent "down" pulses to by pass the first decade counting

circuit and appear at the second decade "down" pulse input pin D2F15. The second decade relay 0 is already energized because the original readout display shows a "0" in the second readout window from the right. Thus, the "down" pulse line is now continuous from the amplifier "down" pulse output pin AF8 to pin D3F15. The balance potential at chopper pin 2 is still higher at +79.500 volts than the -79.503 volts at pin 4 of the chopper. The second "down" pulse enters the third decade counting circuit and reduces the readout display to "+79.000". The third decade relay 0 is now energized, allowing the third "down" pulse to enter the counting circuit of the fourth decade to momentarily reduce the visual readout display to "+70.000". The fourth "down" pulse arrives at D5F16 through the now closed relay 0 contacts of decades 1, 2, 3, and 4, and the normally closed contacts of decimal-polarity relay 0. Thus, the fourth "down" pulse reduces the readout display to "+00.000". When the fifth decade relay 80A closes to energize the fifth decade readout "0" indicator lamp, the decimal polarity relay 0 is also energized. Closure of the normally open decimal-polarity relay 0 contacts connects the "down" pulse line from the fourth decade to both grids of the automatic polarity control tube V5 (on the decimal-polarity board) through a pair of 50 micromicrofarad coupling condensers.

Since the input voltage of -79.503 volts at chopper pin 4 is still lower (less positive) in potential than zero volts at chopper pin 2, when the readout display is "+00.000", the amplifier continues to send out "down" pulses. The fifth "down" pulse (after input voltage polarity reversal) is applied to the grids of decimal-polarity V5 through the now closed, normally open, contacts of decimal-polarity relay 0. This "down" pulse has no effect on the existing conduction of the second triode section of V5, which energizes chassis relays 1 and 2. The appearance of the "down" pulse at pin 7 of V5 biases the first triode section of V5 to conduction and thereby energizes decimal-polarity relays 12, 17, and 18. The newly established conduction in the first section of V5 causes the potential at pin 6 of V5 to decrease, which in turn appears at pin 2 of V5 as a negative pulse. This negative pulse biases the second section of V5 to cut-off and thereby de-energizes chassis relays 1 and 2. The consequent rise in potential at pin 1 of V5 maintains conduction of the first triode sec-



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tion of V5 even after the initiating fifth "down" pulse has disappeared.

De-energization of chassis relays 1 and 2 reverses the polarity of the reference battery voltage applied to the compensating and feedback resistor strings in series. When chassis relays 1 and 2 are de-energized, the potential at chopper pin 2 is always zero or negative with respect to the grounded pin D1R3. Energization of decimal-polarity relay 12 removes +28 volts direct current from the visual readout "+" indicator lamp and applies it through the now closed, normally open relay 12 contacts to the visual readout "-" indicator lamp. Energization of decimal-polarity relay 17 disconnects the decade "up" pulse line (D1F18) from the amplifier "up" pulse output pin AF7 and connects it to the amplifier "down" pulse output pin AF8.

Simultaneous energization of decimal-polarity relay 18 disconnects the decade "down" pulse line (D1F15) from the amplifier "down" pulse output pin AF8 and connects it to the amplifier "up" pulse output pin AF7. As a result of energizing the decimal-polarity relays 17 and 18, the decades recognize "down" pulses from the amplifier as "up" pulses, and "up" pulses from the amplifier as "down" pulses. Thus, when the visual readout displays a "-" sign, the decades count upward upon receipt of "down" pulses from the amplifier. "Down" pulses which cause the decades to count upward (when the visual readout indicates a "-" sign) shall henceforth be called "-up" pulses. When the visual readout displays a "-" sign, "up" pulses from the amplifier cause the decade counter tubes to assume the state shown in Table IV for the "0" digit readout display. "Up" pulses which cause the decade counter tubes to assume the "0" state shall henceforth be referred to as "-down" pulses.

After energization of decimal-polarity relay 12 has changed the visual readout polarity display from "+" to "-", the negative potential on chopper pin 2 is still too high (too positive) with respect to the -79.503 volts at chopper pin 4. The chopper samples the potentials at pins 4 and 2, and sends an error signal to the amplifier which results in the appearance of "-up" pulses at the decades. The decades now count upward in the manner described on page 33 (Automatic Feedback Voltage Syn-

thesis) until the synthesized balance potential at chopper pin 2 equals the input potential at chopper pin 4. When this equality has been established, the error signal becomes zero; and no further pulses are delivered by the amplifier to the decades. The visual readout now displays "-79.503" and the digital voltmeter is said to have reached a balance.

-----Change of Readout Display From "-" to "+"

Detailed functional operation of automatic polarity indication components for a change in readout display from "-00.050" to "+00.050" is described below. The following discussion is centered about a numerical readout display of "00.050" rather than the previously chosen "79.503" in order to demonstrate that the logic of the automatic polarity indication circuit components is unaffected by the numerical display of the readout, and to further expand an appreciation of decade circuit action.

When the visual readout displays "-00.050" volts, the following relays in the automatic polarity control circuits are energized:

- a. Relay 0 in decades 1, 3, and 4.
- b. Relay 81A in decade 5.
- c. Relay 0 on decimal-polarity board.
- d. Relays 17 and 18 on decimal-polarity board.
- e. Relay 12 on decimal-polarity board.

Under this same condition the following relays in the automatic polarity control circuits are de-energized:

- a. Chassis relays 1 and 2.
- b. Relay 0 in decade 2.

If the input voltage to the instrument is now suddenly changed from -00.050 to +00.050 volts, the balance potential at chopper pin 2 will be lower (less positive) than the input potential

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at chopper pin 4. The resulting output of "-down" pulses (bona fide "up" pulses) from the amplifier will change the readout indication first to "-00.000" and then to "+00.000", leaving the decimal-polarity relays 12, 17, and 18 in the de-energized position. De-energization of relay 12 changed the "-" readout display to "+".

De-energization of relays 17 and 18 permits the decades to recognize amplifier output "up" pulses as bona fide "up" pulses at the decade up-pulse input terminal D1F18. "Down" pulses from the amplifier are recognized as bona fide "down" pulses at the decade down-pulse input terminal D1F15. After de-energization of relays 17 and 18 the amplifier recognizes that the potential at chopper pin 2 is lower than that at chopper pin 4. The resulting "up" pulses will cause the readout indication and balance voltage to increase to "+00.050" volts, at which time the error signal becomes zero and the digital voltmeter is said to have reached a balance.

## AUTOMATIC DECIMAL SHIFT AND RANGING CIRCUITS

### ----REQUIREMENTS

Multi-range digital voltmeters having automatic decimal shift and ranging provisions automatically displays in the visual readout an illumined decimal point in the positions shown in Table IX.

### ----DESCRIPTION

The circuits and components involved in the automatic decimal shift and ranging functions are shown in the decimal-polarity and range unit blocks of Figure 13. They are identical in all models of digital voltmeters which incorporate these automatic features.

Figures 6, 7, and 8 show the decimal shift circuits and associated components isolated from the rest of the digital voltmeter circuitry in order to facilitate a grasp of the functional

aspects of the circuit action in shifting from one range of operation to another.

#### ----FUNCTIONAL OPERATION

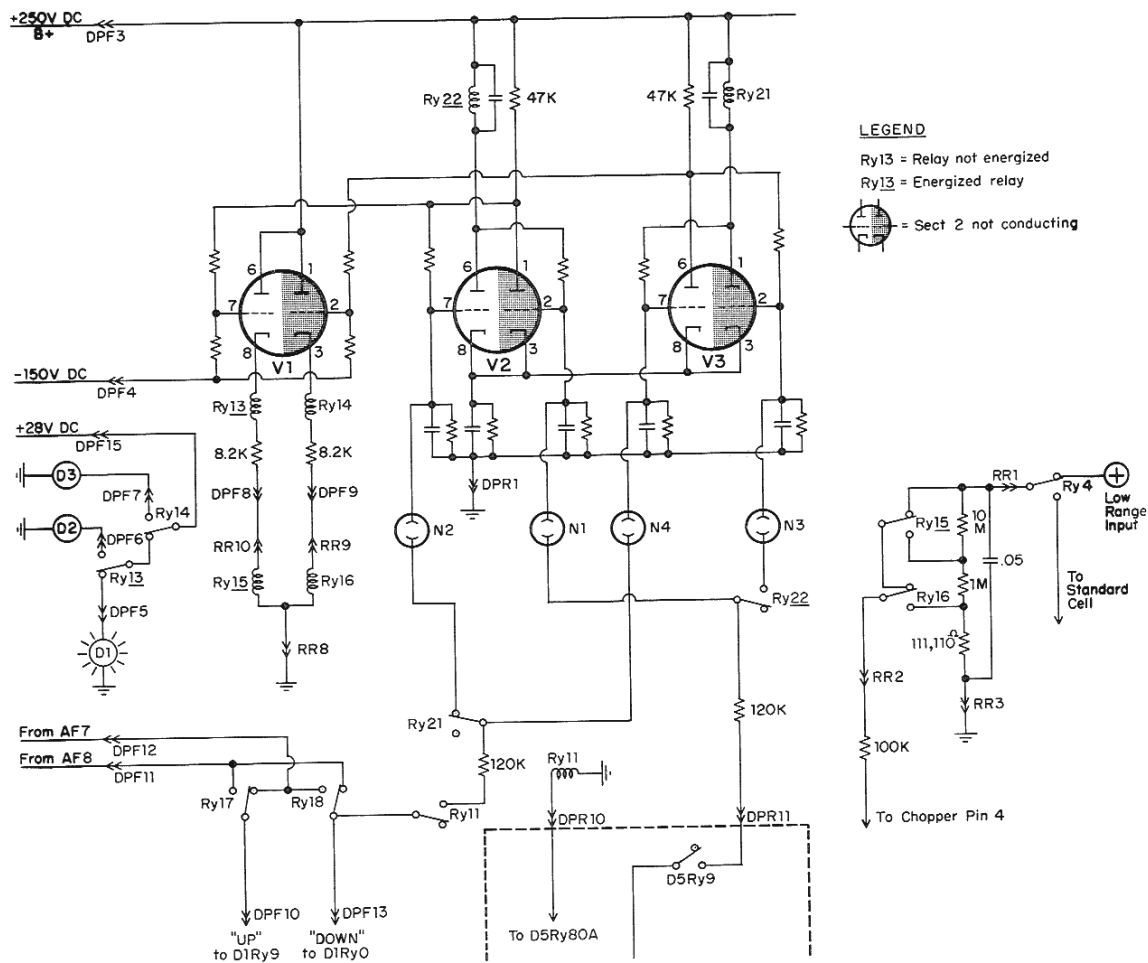
Reference to Table IX indicates that digital voltmeters having a 5 digit readout display are presently limited to two-range operation. In order to describe fully all possible transitions from one operating range to another, the functional description contained herein is based on a four-digit instrument. Extensions of functional operation to 5-digit and 3-digit instruments can readily be made by observing the appropriate numerical limitations appearing in Table IX.

Table IX Decimal Point Locations in Multi-range Digital Voltmeters.

DIGITAL VOLT - METER TYPE	RANGE	MEASURES FROM	VOLTAGES TO	DECIMAL POINT LOCATION
5 Digit	Low	00.001	99.999	Position 1
	Middle	099.99	999.99	Position 2
	High	---	---	---
4 Digit	Low	0.001	9.999	Position 1
	Middle	09.99	99.99	Position 2
	High	099.9	999.9	Position 3
3 Digit	Low	.001	.999	Position 1
	Middle	.99	9.99	Position 2
	High	09.9	99.9	Position 3

# SECTION 3 ——— THEORY OF OPERATION

**Figure 6** State of Automatic Decimal and Ranging Components in a 3-Range Instrument When Operating in the Low Range.



## -----Initial Conditions -- Low Range

Figure 6 shows the state of the automatic decimal and ranging circuit components when operated in the range from 0.000 to 9.999 volts. Note that the first triode sections of V1, V2, and V3 are conducting, and the second triode sections of these tubes are not conducting. The circuitry associated with V2 and V3 is arranged in such a manner that both sections of V2 or V3 never conduct simultaneously. Non-conducting triode sections are indicated in Figure 6 by cross-hatched areas. Identifying symbols of energized relays are underlined. Relay contacts are shown in their energized or de-energized positions, as required by the states of the associated relay operating coils.

Conduction in the first triode section of V1 energizes the operating coils of decimal-polarity relay 13 and range relay 15. The energizing of relay 13 applies 28 volts direct current to the visual readout lamp D1 through the normally closed relay 14 contacts and the now closed, normally open, contacts of relay 13. Application of voltage to lamp D1 illumines the decimal point in position 1 between the third and fourth digits from the right.

In the low range mode of operation, the unknown input voltage is applied from the top of the ranging resistor string to chopper pin 4 through:

- a. The now closed, normally open, contacts of range relay 15.
- b. The normally closed contacts of range relay 16.

In low range operation, the voltage applied to chopper pin 4 is equal to the unknown input voltage.

## -----Shift From Low Range to Middle Range

Let us assume that the visual readout displays "+9.999" volts. In this condition, the transfer relay 9 in each decade is energized, establishing a direct path for "up" pulses from DPF10, through the four decades, to DPR11. If the input voltage is now increased by 0.001 volts, a consequent "up" pulse appears at DPR11 and is applied to the grid of the second triode section of V2 (pin 2). This "up" pulse at pin 2 biases section 2 of V2 to

## SECTION 3 ————— THEORY OF OPERATION

conduction as shown in Figure 7. When section 2 of V2 conducts, the potential at pin 1 of V2 and the potentials at pin 7 of V1 and V2 decrease below cut-off. This results in non-conduction in the first triode sections of V1 and V2.

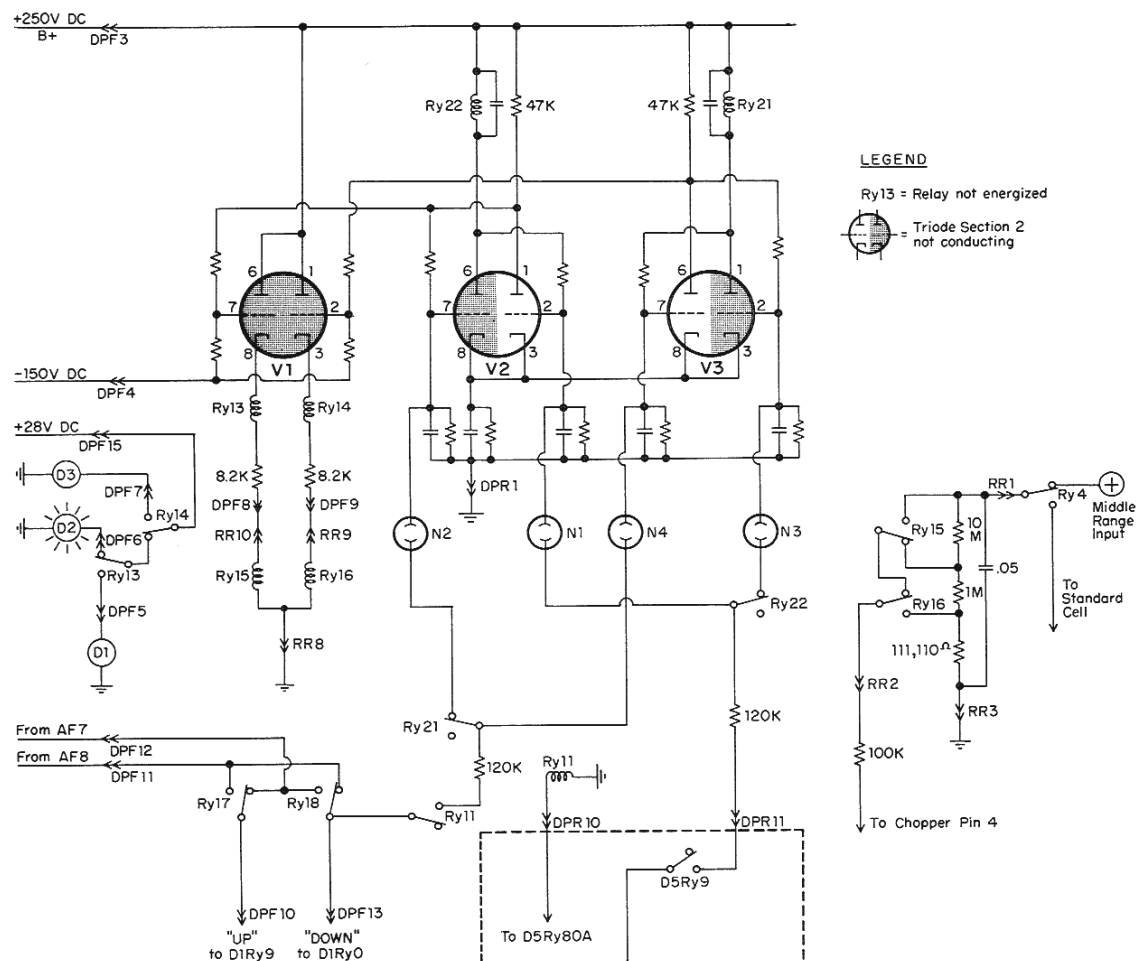
Cut-off of section 1 of V2 de-energizes relay 22 and restores closure of the normally closed relay 22 contacts in series with DPR11 and grid 2 (pin 2) of V3 in preparation for a possible subsequent shift from middle to high range operation.

Cut-off of section 1 of V1 de-energizes decimal-polarity relay 13 and range relay 15. The de-energizing of relay 13 transfers +28 volts direct current from visual readout lamp D1 to lamp D2. The illumined decimal point now appears in the decimal #2 position between the second and third digits from the right. The de-energizing of relay 15 transfers the connection of chopper pin 4 from the top to the bottom of the 10 megohm string of ranging resistors. This shift in connection of chopper pin 4 results in a decrease of potential at chopper pin 4 by a factor of 10.

Immediately after the de-energizing of relay 13 and relay 15, the numerical display of the visual readout is "+99.99" volts, while the input to the digital voltmeter is +10.00 volts and the potential at chopper pin 4 is 1.000 volts. At this instant the feedback voltage synthesized within the digital voltmeter is 9.999 volts. The error signal resulting from the difference in potential at chopper pin 4 and the synthesized feedback voltage at chopper pin 2 causes the amplifier to send out sufficient "down" pulses to decrease the readout display to "+00.00" which corresponds to a zero feedback voltage. After this momentary display of "+00.00", the amplifier sends out "up" pulses and the balance voltage is built up in the manner described on page 33 (Automatic Feedback Voltage Synthesis) until it is equal to 1.000 volts.

At this time, the visual readout displays "+10.00" volts. The digital voltmeter is now operating in the middle range from 10.00 to 99.99 volts, and the decimal point in the visual readout is correctly positioned between the second and third digits from the right. Note that the sensitivity of the digital voltmeter is now  $\pm 10$  millivolts. Figure 7 shows the state of the automatic decimal and ranging circuit components when the digital

**Figure 7** State of Automatic Decimal and Ranging Components in a 3-Range Instrument When Operating in the Middle Range.





## SECTION 3 ————— THEORY OF OPERATION

voltmeter is operating in the middle range.

### -----Shift From Middle to High Range

Let us now assume that the applied voltage and visual readout display are "+99.99" volts. If the input voltage is now increased by 00.01 volts, a consequent "up" pulse is transmitted from DPR10, through the now closed relay 9 contacts in the four decades, to DPR11 from whence it is conducted to the second triode grids (pin 2) of V2 and V3 as shown in Figure 7. The positive "up" pulse appearing at grid 2 of V2 has no effect because the second section of V2 is already conducting. However, the appearance of the "up" pulse at grid 2 of V3, biases section 2 of V3 to conduction. As a result of this conduction, the potential at pin 1 of V3 decreases, which in turn biases section 1 of V3 to cut-off. Non-conduction of section 1 of V3 causes the potential at pin 6 of V3 to rise. This rise is communicated to pin 2 of V3 and maintains conduction of section 2 of V3 even after the initiating "up" pulse has disappeared. Further, the rise in potential at pin 6 of V3 biases section 2 of V1 to conduction. This conduction energizes decimal-polarity relay 14 and range relay 16.

The energizing of relay 14 transfers +28 volts direct current from visual readout lamp D2 to lamp D3. The illuminated decimal point now appears in the decimal #3 position between the first and second digits from the right. The energizing of relay 16 transfers the connection of chopper pin 4 from the junction of the 10 megohm and 1 megohm ranging resistors to the junction of the 1 megohm and 111, 110 ohm ranging resistors. This shift in connection of chopper pin 4 results in a decrease of potential at chopper pin 4 by a factor of 10.

Immediately after the energizing of relay 14 and relay 16, the numerical display of the visual readout is "+999.9" volts, while the input to the digital voltmeter is 100.0 volts and the potential at chopper pin 4 is 1.000 volts. At this instant, the feedback voltage synthesized within the digital voltmeter is 9.999 volts. The error signal resulting from this difference in potential at chopper pin 4 and the synthesized feedback voltage at chopper pin 2 causes the amplifier to send out sufficient "down" pulses to decrease the readout display to "+000.0", which corresponds to a zero feedback voltage.

After momentary readout display of "+000.0" the amplifier sends out "up" pulses and the feedback voltage is built up in the manner described on page 33 (Automatic Feedback Voltage Synthesis) until it is equal to the chopper pin 4 potential of 1.000 volts. At this time, the visual readout displays "+100.0" volts. The digital voltmeter is now operating in the high range from 100.0 to 999.9 volts and the decimal point in the visual readout is positioned between the first and second digits from the right. Note that the sensitivity of the digital voltmeter is  $\pm 100$  millivolts when operating in the high range. Figure 8 shows the state of the automatic decimal and ranging circuit components when the digital voltmeter is operating in the high range.

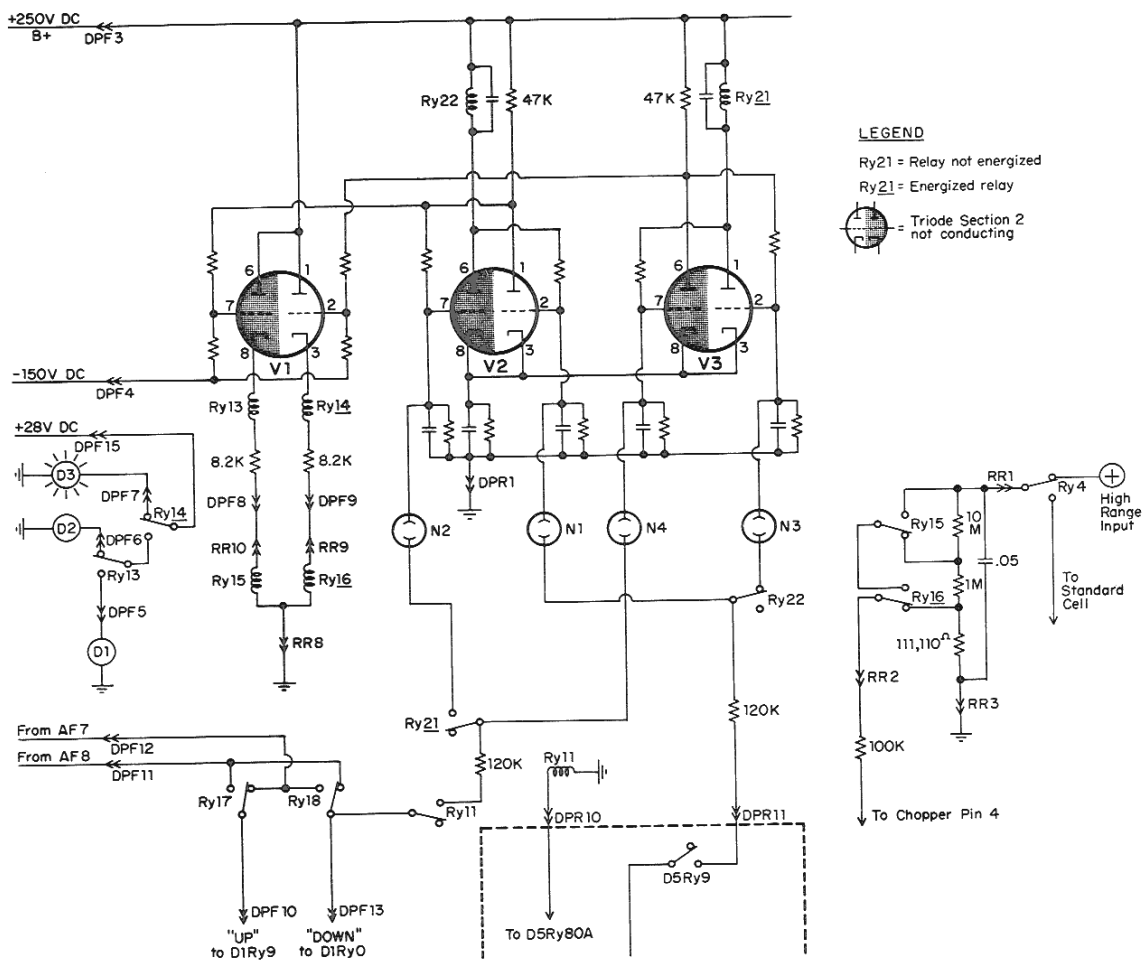
#### -----Shift From High to Middle Range

Let it be assumed that the applied voltage and visual readout display are "+100.0" volts. If the input voltage is decreased by 100 millivolts the readout display changes from "100.0" to "099.9" volts. In this condition, we note that the readout window associated with the fourth decade displays a "0". Reference to Table IV and the Decade 1 circuit diagram in Figure 13 shows that relay 80A in any decade is energized whenever the counter tubes in that decade are in the "zero" condition. The energizing of relay 80A on decade 4 in turn energizes decimal-polarity relay 11. The energizing of relay 11 closes the normally open relay 11 contacts, thereby establishing continuity for a subsequent down pulse from the armature of decimal-polarity relay 18 to the armature of relay 21 through a 120,000 ohm resistor. Note in Figure 8 that during operation in the high range the second triode sections of V1, V2, and V3 are conducting, and the normally closed contacts of relay 21 are open.

When the voltage applied to the digital voltmeter is reduced to 99.9 volts, the readout display becomes "+099.9" and the potentials at chopper pin 4 and chopper pin 2 are equal at 0.999 volts. If the voltage applied to the digital voltmeter is now decreased to 99.8 volts, the chopper pin 4 potential decreases to 0.998 volts. The resulting 1 millivolt error signal causes the amplifier to send out a "down" pulse to the decades which momentarily changes the readout display to "+099.0" volts and changes the feedback voltage at chopper pin 2 to 0.990 volts. However, this same "down" pulse is also applied to pin 7 of V3 through the now closed relay 11 contacts and the neon bulb N4. The ap-

## SECTION 3 ——— THEORY OF OPERATION

**Figure 8** State of Automatic Decimal and Ranging Components in a 3-Range Instrument When Operating in the High Range.



pearance of this "down" pulse at pin 7 of V3 biases the first triode section of V3 to conduction. This conduction causes a decrease in potential at pin 6 of V3 resulting in a bias below cut-off at pin 2 of V3. Cut-off of section 2 of V3 de-energizes relay 21 causing closure of the armature of relay 21 to the normally closed relay 21 contact which is connected to pin 7 of V2 through the neon lamp N2. Cut-off of section 2 of V3 causes the potential at pin 1 of V3 to rise. This rise in potential appears at pin 7 of V3 and maintains conduction of section 1 of V3 after the initiating pulse has disappeared. The decrease in potential at pin 6 of V3 resulting from conduction in section 1 of V3 also biases section 2 of V1 to cut-off, thereby de-energizing decimal-polarity relay 14 and range relay 16.

The de-energizing of relay 14 transfers +28 volts direct current from visual readout lamp D3 to lamp D2. This transfer causes the momentary readout display to change from "+099.0" to "+09.90".

The de-energizing of relay 16 disconnects chopper pin 4 from the junction of the 1 megohm and 111, 110 ohm ranging resistors and connects it to the junction of the 10 megohm and 1 megohm ranging resistors. This shift in connection of chopper pin 4 results in an increase of potential at chopper pin 4 by a factor of 10, or an increase from .998 to 9.98 volts. At this instant, the potential at chopper pin 2 is 0.990 volts. The difference between the potentials at chopper pin 4 and chopper pin 2 results in the output of amplifier pulses which build up the feedback voltage in the manner described on page 33 (Automatic Feedback Voltage Synthesis) until it is equal to the potential of 9.980 volts at chopper pin 4.

The voltage applied to the digital voltmeter is now 99.80 volts. The attenuated voltage applied to chopper pin 4 is 9.980 volts and is equal to the feedback voltage of 9.980 volts at chopper 2. If a tolerance of  $\pm 0.1\%$  is applied, the readout display may range 100 millivolts above or below the nominal readout display of "+99.80" volts. Under these conditions, the digital voltmeter is operating in the middle range, and the decimal point in the visual readout is properly positioned between the second and third digits from the right. Figure 7 shows the state of the automatic decimal shift and ranging circuit components when the digital voltmeter is operated in the middle range.

## SECTION 3 ————— THEORY OF OPERATION

### -----Shift From Middle to Low Range

Refer to Figure 7 for the initial conditions of the automatic decimal shift and ranging circuit components when the digital voltmeter is operated in the middle range. Assume that the visual readout display and input to the voltmeter are "+10.00" volts. A 10 millivolt decrease in applied voltage will cause the readout display to change from "+10.00" to "+09.99" volts, and the attenuated input voltage applied to chopper pin 4 will be equal to the balance voltage of 0.999 volts at chopper pin 2. A "0" in the fifth decade position indicates closure of the decade 5 relay 80 contacts and consequent energizing of decimal polarity relay 11. This in turn closes the normally open contacts of relay 11.

If the voltage applied to the digital voltmeter is now decreased from 9.99 volts to 9.98 volts, the chopper pin 4 potential decreases from 0.999 to 0.998 volts, while the potential at chopper pin 2 momentarily remains constant at 0.999 volts. The resulting 1 millivolt error signal causes the amplifier to send out a "down" pulse to the decades which momentarily changes the visual readout display to "+09.90" volts, and momentarily changes the feedback voltage at chopper pin 2 to 0.990 volts.

However, this same "down" pulse is also applied to pin 7 of V2 and V3 through the now closed relay 11 contacts and neon bulbs N2 and N4, respectively. Appearance of the "down" pulse at pin 7 of V3 has no effect on section 1 of V3 because it is already conducting. Application of the "down" pulse to pin 7 of V2, however, biases section 1 of V2 to conduction. This conduction causes a decrease in potential at pin 6 of V2, which is communicated to pin 2 of V2 and biases section 2 of V2 to cut-off. Cut-off of section 2 of V2 causes the voltage at pin 1 to rise. This rise in voltage appears at pin 7 of V2 and maintains conduction of section 1 of V2 after the initiating "down" pulse has disappeared. The rise in voltage at pin 1 of V2 also appears at pin 7 of V1 and biases section 1 of V1 to conduction. Conduction in section 1 of V1 energizes decimal-polarity 13 and range relay 15.

The energizing of relay 13 transfers +28 volts direct current from visual readout lamp D2 to lamp D1. This transfer causes the momentary readout display to change from "+09.90" to the

" $\pm 0.990$ ".

The energizing of relay 15 disconnects chopper pin 4 from the junction of the 10 megohm and 1 megohm ranging resistors and connects it to the top end of the ranging resistor string. This shift in connection of chopper pin 4 results in an increase of potential at pin 4 by a factor of 10, or an increase from 0.998 to 9.980 volts. At this instant, the potential at chopper pin 2 is 0.990 volts. The error signal resulting from the difference in potential at chopper pin 4 (9.98 volts) and chopper pin 2 (0.990 volts) cause the amplifier to send up pulses to the decades. These pulses build up the feedback voltage until it is equal to the potential of 9.98 volts at chopper pin 4.

The voltage applied to the digital voltmeter is now 9.98 volts and is equal to the potential applied to chopper pin 4 and to the balance voltage at chopper pin 2. If a tolerance of  $\pm 0.1\%$  is applied, the readout display may range 10 millivolts above or below the nominal readout display of " $\pm 9.980$ " volts. Under these conditions the digital voltmeter is operating in the low range and the decimal point in the visual readout is correctly positioned between the third and fourth digits from the right. Figure 6 shows the state of the automatic decimal shift and ranging circuit components when the digital voltmeter is operated in the middle range.

## RECORDING CIRCUITS

### ----REQUIREMENTS

A recorder, operated in conjunction with the Model 519-P Digital Voltmeter, must be capable of making a record of any voltage applied to the instrument in the range from  $\pm 00.000$  to  $\pm 999.99$  volts. Command to record shall be supplied by momentary manual closure of a print command switch.

### ----DESCRIPTION

Connection of a printer to operate in conjunction with a digital voltmeter is shown in Figure 5. Detailed print control circuits which are built into the Model 519-P Digital Voltmeter are

## SECTION 3 ————— THEORY OF OPERATION

shown in Figure 13. On each decade are mounted a series of buffer relays, one of which is connected in parallel with each numerical readout lamp in that decade. Relays 4, 5, 6, and 7 on the decimal polarity board constitute the buffer relays for the three possible decimal points and the minus sign. Decimal-polarity relay 1 deactivates the instrument during the printing cycle. Decimal polarity relay 2 and decimal polarity relay 3 operating in tandem control 115 volts alternating current to the printer solenoids. V4 on the decimal polarity board keeps relay 1 and relay 2 energized while the digital voltmeter is coming to a balance after momentary manual operation of the print command switch.

### ----FUNCTIONAL OPERATION

#### -----Initial Conditions

Let us assume that a print cycle has just been completed, and the visual readout display is equal to the applied voltage at "-79.503" volts. Under these conditions, the print command switch is open, V4 is not conducting and relay 1 and relay 2 are de-energized. When relay 1 is not energized, the cathodes of the amplifier 5696 thyratrons are short circuited to ground through the normally closed relay 1 contacts, rendering the digital voltmeter inactive. A 1 microfarad condenser is connected across the coil of relay 3 but relay 3 is not now energized because the charge on the 1 microfarad condenser has been dissipated during the previous print cycle. For a readout display of "-79.503" the following buffer relays are energized:

<u>- 7 9 . 5 0 3</u>	<u>BOARD</u>	<u>RELAY NO.</u>
3	Decade 1	103
0	Decade 2	100
5	Decade 3	105
.	Decimal-Polarity	4
9	Decade 4	109
7	Decade 5	107
-	Decimal-Polarity	7

-----Recording

Let the voltage applied to the digital voltmeter now be changed to +305.97 volts. The readout display will not immediately change from the previous display of "-79.503". If it is desired to make a printed record of the new voltage applied to the instrument it is necessary to operate momentarily the print command switch. Closure of the print command switch applies B+ voltage to pin 2 of V4 causing the first triode section of V4 to conduct. Conduction in section 1 of V4 is also applied to pin 7 of V4 through a 1 megohm resistor and causes the second triode section of V4 to conduct.

Conduction in section 2 of V4 energizes relay 1 and relay 2. The energizing of relay 1 removes the 5696 thyatron cathodes from ground and thus activates the digital voltmeter. The amplifier now sends pulses to the decade counter circuits while pulses from the 5696 thyatrons are applied to pin 2 of V4. The pulses at pin 2 of V4 cause the first triode section to conduct pulses at the same rate as the pulses arriving at pin 2. The resistance-capacitance network in the cathode circuit of the first section of V4 maintains the voltage at pin 7 of V4 above cut-off resulting in continuous conduction in section 2 of V4 as long as the amplifier thyatron cathodes supply pulses to pin 2 of V4. Energization of relay 2 connects the 1 microfarad condenser to B+ through the now closed, normally open, relay 2 contacts and a 100,000 ohm resistor permitting the 1 microfarad condenser to charge while the instrument is arriving at a balance. At balance, the visual readout display equals the applied voltage of "+305.97" volts, and the buffer relays indicated below are energized:

	<u>BOARD</u>	<u>RELAY NO.</u>
+ 3 0 5 . 9 7		
	Decade 1	107
	Decade 2	109
	Decimal Polarity	5
	Decade 3	105
	Decade 4	100
	Decade 5	103
	None	None



### SECTION 3 ————— THEORY OF OPERATION

After the digital voltmeter has reached a balance, no more pulses are supplied to pin 2 of V4 from the amplifier thyatron cathodes. This absence of pulses at pin 2 of V4 results in cut-off of sections 1 and 2 of V4. Cut-off in section 2 of V4 de-energizes relay 1, thereby short-circuiting the amplifier thyatron cathodes to ground through the normally closed relay 1 contacts. Short-circuiting the amplifier thyatron cathodes to ground deactivates the digital voltmeter during the following print cycle. The de-energizing of relay 2 disconnects the 1 microfarad condenser from B+ and applies the charge stored in the condenser to the coil of relay 3. The discharge of the condenser through the coil of relay 3 momentarily closes the normally open contacts of relay 3 until the condenser charge has been dissipated. Momentary closure of the normally open relay 3 contacts applies 115 volts alternating current to the decimal #2 printer solenoid through the now closed decimal-polarity relay 5 contacts. The 3, 0, 5, 9, and 7 amount solenoids in the printer are also energized through the previously closed buffer relays on the decades. The normally open stationary contact of relay 3 is connected to a common decade buffer relay contact line by means of an external jumper in the printer cable assembly from pin DPV10 to pin V11 on all decades. Momentary closure of the normally open relay 3 contacts also energizes the add solenoid in the printer through pin DP10. The energizing of this add solenoid initiates the print cycle. The printer now makes a printed record of "+305.97" volts which equals the applied voltage and the visual readout display.

After a printout has been completed, the digital voltmeter holds the visual readout display corresponding to the printed record (even if the input voltage is changed) until the print command switch is again operated momentarily. The "+01.108" volt visual display after calibration can be recorded in the same manner as unknown input voltages applied to the instrument, provided the "1.018V" switch is left in the ON position. It should be noted that the voltage applied to the digital voltmeter may be monitored between printouts by maintained closure of the print command switch. In this condition, the instrument is held in an activated condition and the readout will correspond to the applied voltage. Printout is not accomplished after balance unless the print command switch is opened.

# OPERATION AND SERVICE MANUAL

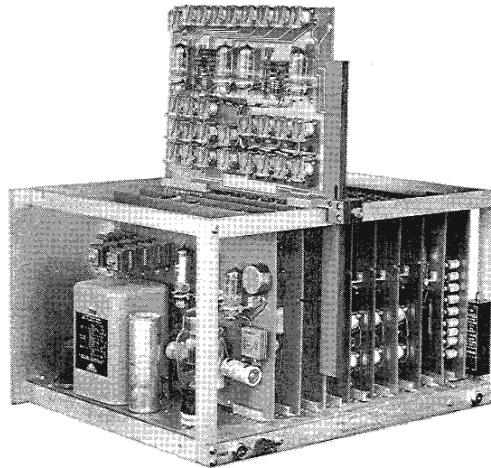
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NOTES:

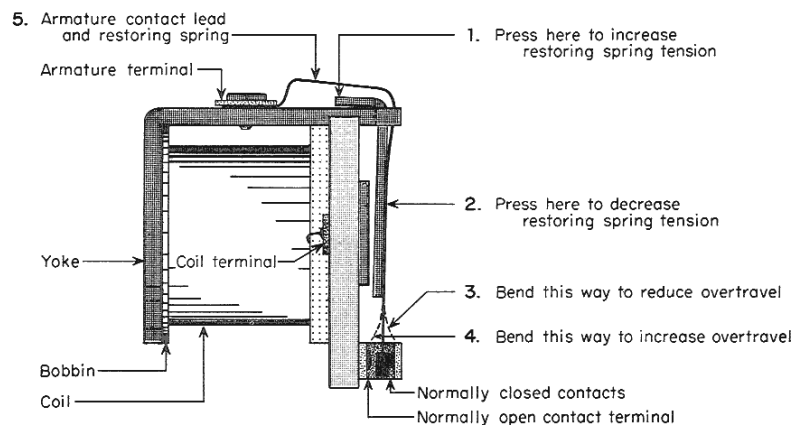
### SECTION 3 ——— THEORY OF OPERATION

NOTES:

**Figure 9** Use of an Extension Board and Clamp in Making Adjustments to Decade and Decimal Polarity Relays.



**Figure 10**  
**Left Side View**  
**Decade Relay.**



1. To INCREASE time required for relay to operate upon energization:
  - a. Bend movable contact arm as shown in (4) above.
  - b. Bend restoring spring (5) to increase restoring spring tension.
  - c. Increase gap between stationary contacts.
2. To DECREASE time required for relay to operate upon energization:
  - a. Bend movable contact arm as shown in (3) above.
  - b. Bend restoring spring (5) to decrease restoring spring tension.
  - c. Decrease gap between stationary contacts.
3. To INCREASE operated time upon de-energization:
  - a. Bend movable contact arm as shown in (3) above to decrease gap between armature and core face.
  - b. Bend restoring spring to decrease restoring spring tension.
4. To DECREASE operated time upon de-energization:
  - a. Bend movable contact arm as shown in (4) above.
  - b. Bend restoring spring to increase restoring spring tension.

## SECTION 4 CONTENTS

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## OPERATIONAL ADJUSTMENTS

## ----CALIBRATION

The digital voltmeter should be calibrated before use, and at periodic intervals throughout the day. Follow the simple calibration procedure given on page 17. Consult the standard cell certificate in Figure 2 for the correct calibration voltage when using the instrument in extreme ambient temperatures.

## ----AMPLIFIER GAIN

For best operation, the digital voltmeter should be operated at an amplifier gain setting of 1 millivolt. When amplifier gain is not high enough, the visual readout display will not respond to input voltage changes of 1 millivolt. Excessively high amplifier gain may cause instability in the readout window associated with the first decade. The following procedure should be followed when adjusting amplifier gain:

1. Maintain closure of the print command switch.
2. Momentarily operate the "1.018V" switch and observe a readout display in the general range of "01.018" volts.
3. Slowly turn the slotted calibration rheostat shaft, which is located in the lower left corner of the front panel, in a counter-

clockwise direction. Observe the magnitude of the decrease in readout display. If the readout display decreases in steps of 1 millivolt and no instability is encountered in the readout window associated with the first decade, no adjustment of amplifier gain should be made.

4. If slowly rotating the calibration rheostat shaft counter-clockwise results in a decrease of 2 or more millivolts in the readout display, the amplifier gain should be increased by turning the slotted gain control potentiometer shaft a small amount in the clockwise direction. Recheck the amount of readout display dropoff and repeat amplifier gain adjustment if necessary. In general, the gain is set properly when the amplifier gain control shaft is positioned approximately midway between the stops.
5. If instability develops in the readout window associated with the first decade, turn the gain control counter-clockwise until instability disappears, and the readout display decreases in steps of 1 millivolt as the calibration rheostat shaft is turned slowly counter-clockwise.
6. Adjust the calibration rheostat shaft until the readout display is "+01.018". Upon release of the print command switch, the printer will make a record of the 1.018 calibration voltage.
7. Momentarily operate the "1.018V" switch. The gain and calibration settings have been properly made and the digital voltmeter is now ready for use.

#### ----HUM CONTROL

A hum control adjustment is provided on the power supply board to minimize the difference between positive and negative numerical readout displays when the input voltage is held constant in magnitude but reversed in polarity. To set the hum control adjustment properly, follow the procedure given below:

1. Apply a positive voltage in the lower end of the middle range to the input leads of the digital voltmeter.
2. Slowly decrease the input voltage until the readout display is "+099.99" volts.

3. Slowly decrease the input voltage until the decimal point shifts one place to the left. Immediately stop decreasing the input voltage as soon as the readout display starts to change from the "+099.99" volts.
4. Allow the readout display to become stabilized. Note the magnitude and polarity of the readout display. As pointed out previously, the nominal readout display is "+99.980" volts. Application of +.01% tolerance permits a readout display in the range from "+99.990" to "+99.970" volts immediately after a shift of decimal point from position 2 to position 1. For purposes of illustration, let us assume that the readout display changes from "+099.99" to "+99.995".
5. Reverse the polarity of the input voltage to the digital voltmeter and repeat steps 1 through 4 above. Note the readout display. Let us assume that it is "-99.985" volts.
6. Adjust the hum control potentiometer shaft and repeat steps 1 through 5 above, noting the stabilized positive and negative readout displays immediately after decimal shift to position 1. Repeat this procedure several times if necessary, until the positive and negative numerical readout displays fall into the range from 99.990 to 99.970. The hum control is now properly adjusted and need not be adjusted again unless the stray pickup at the test site changes appreciably.

#### REFERENCE BATTERY REPLACEMENT

The reference battery is composed of a series of Mallory Type RM-1 mercury "A" cells stacked in phenolic tubes. These cells have a useful life of 1000 hours at a current drain of 1 milli-ampere. Inability to obtain a visual readout display below the "+01.018" volts when the calibration rheostat shaft is turned full counter-clockwise indicates need for replacement of reference battery cells. A too frequent requirement for calibration to "+01.018" volts may indicate the need for battery replacement caused by excessive reference voltage drift.

The reference battery assembly is exposed by removing the bottom plate of the instrument. Each phenolic tube containing mercury cells is fitted with one stationary and one spring loaded

end plug. The spring loaded plug has a projecting boss whose diameter is smaller than the diameter of the stationary plug. The mercury cells are assembled in the phenolic tubes in such a manner that the polarity of the spring loaded end plug is positive. The use of end plugs having different diameters makes it impossible to install improperly the phenolic tube battery assemblies in their holders under the chassis.

Replacement Mallory RM-1 mercury cells may be obtained commercially or from Non-Linear Systems, Inc., Del Mar Airport, Del Mar, California.

## TROUBLE SHOOTING

### ----GENERAL

Maintenance personnel must be thoroughly familiar with the physical makeup of the digital voltmeter, its installation and operating procedures, and the detailed theory of operation given elsewhere in this handbook.

The first step in correcting any trouble or failure that may occur is to isolate the section of the circuit that is causing trouble. Such isolation can be accomplished most readily by considering the circuit as composed of the basic sections shown in the block diagram, Figure 12, and their functional operation as described in detail in this handbook. Improper operation of the digital voltmeter almost always shows up as improper readout display whether in a transitory or stabilized condition. Detailed examination of the readout display in the light of the theory of operation given in this handbook invariably will lead to the source of trouble.

### ----TEST EQUIPMENT

No special test equipment is required for the maintenance of the digital voltmeter. An ordinary oscilloscope is helpful in tracing amplifier output pulses. Resistance and voltage measurements, both alternating and direct current, can be made with a multimeter. An extension board and clamp (see Figure 9) which is available from Non-Linear Systems, Inc., can be used very



effectively in making relay adjustments on the decades and decimal polarity boards.

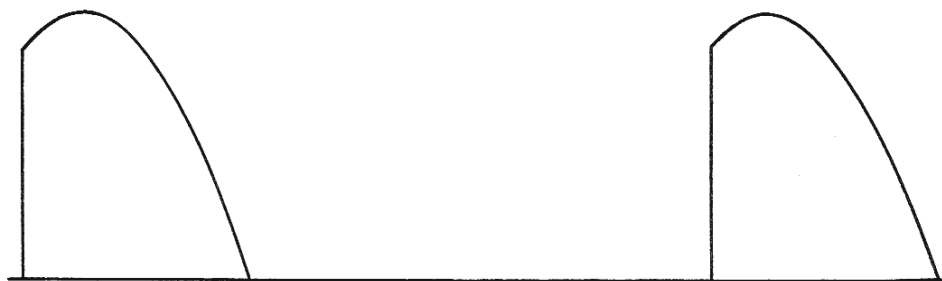
#### ----RELAY ADJUSTMENTS

From the presentation of theory of operation starting on page 21, it becomes evident that properly sequenced relay operation is important to the correct operation of the instrument. Under some conditions it may be necessary to readjust the decade relays restoring spring tensions or contact pressures. After localizing a possible improperly-operating relay by examination and analysis of the readout behavior, the decade containing the suspected relay should be replaced by the extension board as shown in Figure 9. The decade then should be mounted in the plugs located on the top edge of the extension board. Care should be taken to mate the decade terminal tabs with the corresponding contact clips in the plug when mounting the decade board. The digital voltmeter should now be operated in the range where improper readout display has been previously observed. Small exploratory pressures should be applied with a slender, plastic probe at points (1) and (2) on the suspected relays, as shown in Figure 10. The statements appearing in Figure 10 summarize possible relay adjustments in terms of the desired change in relay operating characteristics. Readout display should be monitored when these exploratory pressures are applied. When the readout display becomes correct, a permanent adjustment can be made on the relay to take the place of the exploratory pressures. After making a relay adjustment, the decade board containing the relay should be replaced in its normal position and operation of the digital voltmeter should be checked again in the range which previously gave incorrect operation.

----PULSE TRACING

When viewed on an oscilloscope screen, the "up" and "down" pulses at the amplifier pulse output terminals are of the form shown below.

Figure 11 Wave Shape of "Up" and "Down" Pulses at Amplifier Output Terminals.



----TROUBLE SHOOTING CHART

As an aid in servicing, the Trouble-Shooting Chart, Table X, indicates causes and remedies for certain specific troubles.

Table X Trouble-shooting Chart

SYMPTOM	PROBABLE CAUSE	REMEDY
Entire visual readout fails to light up	"Power" switch in "off" position.	Momentarily operate the "Power" switch to ON position.
	No alternating current line voltage.	Trace line failure.
	Power cable defective.	Repair or replace cable.
	Fuse defective.	Replace fuse.
	No 28 volts direct current.	Check for 28 volts at various points as shown in circuit diagram Figure 13.
Visual readout display fails to change from " + 555.55" indication.	No 250 volts direct current plate voltage available at decade counter tube plates.	Check for 250 volts direct current at PSF6.
		Trace line failure between D1F3 and PSF6.
Some characters in the visual readout display do not light up.	Defective readout indicator lamp.	Replace lamp.
	No 28 volts direct current available at center contact of lamp.	Trace 28 volts direct current line failure.
Unstable display in 1st decade readout window.	Amplifier gain too high.	Adjust amplifier gain as described on page 63.
	Excessive ripple on direct current input lines.	Provide suitable filter between direct current source and digital voltmeter input leads.
	Stray noise voltage pick-up.	Connect chassis of digital voltmeter to a good earth ground.
		Reverse 115 volts alternating current plug in service receptacle.
	Microphonics in 5751 in 1st amplifier stage.	Replace 5751 in amplifier.
	Unstable 5696 thyratrons in amplifier.	Replace 5696 tubes in amplifier.

# OPERATION AND SERVICE MANUAL

Table X Trouble-shooting Chart (continued)

SYMPTOM	PROBABLE CAUSE	REMEDY
Unstable display in any readout display window.	Relay 9 on associated decade is not pulling in.	Confirm presence of operating voltage at coil of associated relay 9.
		Check line voltage ( $115 \pm 10$ volts alternating current 60 cycle).
		Decrease air gap between relay armature and core.
		Reduce relay restoring spring tension.
	Normally open relay 9 contacts not making proper contact.	Increase overtravel of moveable contacts. Check adjustment of relays 81A, 11B, 20A, and 40A for sufficient closed contact time to fully energize coil of relay 9.
Readout display will not increase.	No error signal.	Replace defective chopper. Check error signal line from chopper pin 3 to DR3.
	No amplifier "up" pulse at decade.	Trace "up" pulse line failure from AF1 to decades.
	Defective decade counter tube.	Replace.
	No amplifier "up" pulse at AF7.	Defective amplifier, repair or replace.
Readout display will not decrease.	No error signal.	Replace defective chopper. Check error signal line from chopper pin 3 to DR3.
	No amplifier "down" pulse at AF7.	Defective amplifier, replace or repair.
	No amplifier "down" pulse at decades.	Trace "down" pulse line failure from AF8 to decades.
	Defective decade counter tubes.	Replace.
	Defective neon "down" pulse coupling lamps in decades.	Replace.
Readout display will not increase or decrease.	Decimal-polarity relay 1 deactivates digital voltmeter by shorting amplifier 5956 cathode to ground through normally closed decimal-polarity relay 1 contacts.	Operate print command switch to closed position to energize decimal-polarity relay 1 and thereby activate digital voltmeter.

Table X Trouble-shooting Chart (continued)

SYMPTOM	PROBABLE CAUSE	REMEDY
Readout display decreases in steps of more than 1 digit in extreme right hand window when input voltage is decreased very slowly.	Low amplifier gain.	Adjust amplifier gain as described on page 63.
Visual readout display increases and stays at "9999.9" when input voltage is below "9999.9" volts.	No reference current.	Replace reference battery.
		Re-establish continuity of reference circuit.
Visual readout display decreases to and stays at "+00.000" when input voltage is negative.	Decimal-polarity relay 0 does not transfer "down" pulse into polarity control tube V5 on decimal-polarity board.	Check for "down" pulses at normally open decimal-polarity relay 0 contacts.
		Replace decimal-polarity tube V5 if defective.
		Check operation of decimal-polarity relays 17 and 18.
		Check operation of chassis relays 1 and 2.
Decimal point refuses to shift to the right.	No "up" pulses arriving at pin 2 of decimal-polarity tube V2 or pin 2 of decimal-polarity tube V3.	Replace defective neon bulb N1 or N3.
		Correct faulty decimal-polarity relay 11 contacts.
		Correct faulty closure of D5 relay 1 normally open contacts.
		Correct faulty "up" line through the decades.
Decimal point refuses to shift to left.	No "down" pulses pin 7 arriving at decimal-polarity tube V2 or pin 2 of decimal-polarity tube V3.	Replace defective neon bulb N2 or N4.
		Correct faulty normally closed contacts of decimal-polarity relay 21.
		Correct faulty closure of normally open decimal-polarity relay 11 contacts.
		Correct non-operation of decimal-polarity relay 11.
		Correct faulty normally closed decimal-polarity relay 18 contacts.
		Correct faulty decimal-polarity F12 contact.
		Correct faulty "down" line from amplifier to decimal-polarity board.

# OPERATION AND SERVICE MANUAL

Table X Trouble-shooting Chart (continued)

SYMPTOM	PROBABLE CAUSE	REMEDY
Unstable decimal point location.	Improper restoring spring tension on decimal-polarity relay 21 and decimal-polarity relay 22.	Analyze pattern of readout instability. Using the circuit logic presented on page 29, deduce which decimal shift relays are malfunctioning. Make exploratory modifications of restoring spring tension. Make permanent relay adjustments as required.
Momentary operation of print command switch does not cause printer to operate.	No 115 volts alternating current at printer drive motor.	Plug printer 115 volts alternating current power cord into service receptacle.
	Decimal-polarity relay 1 and relay 2 not operating.	Replace defective decimal-polarity tube V4.
	Decimal-polarity relay 3 not operating.	Correct faulty normally closed relay 2 contact closure.
		Replace faulty 1 microfarad capacitor connected to armature of relay 2.
		Establish presence of 250 volts direct current at normally open contact of relay 2.
	Printer add solenoid is not being powered with 115 volts alternating current.	Correct faulty normally open relay 3 contact closure.
		Install vertical plug on rear edge of decimal-polarity board.
Printout does not agree with visual readout display.	Faulty buffer relay coil energization or contact closure.	Localize and repair defective buffer relay.

SECTION 4 ————— MAINTENANCE

NOTES:

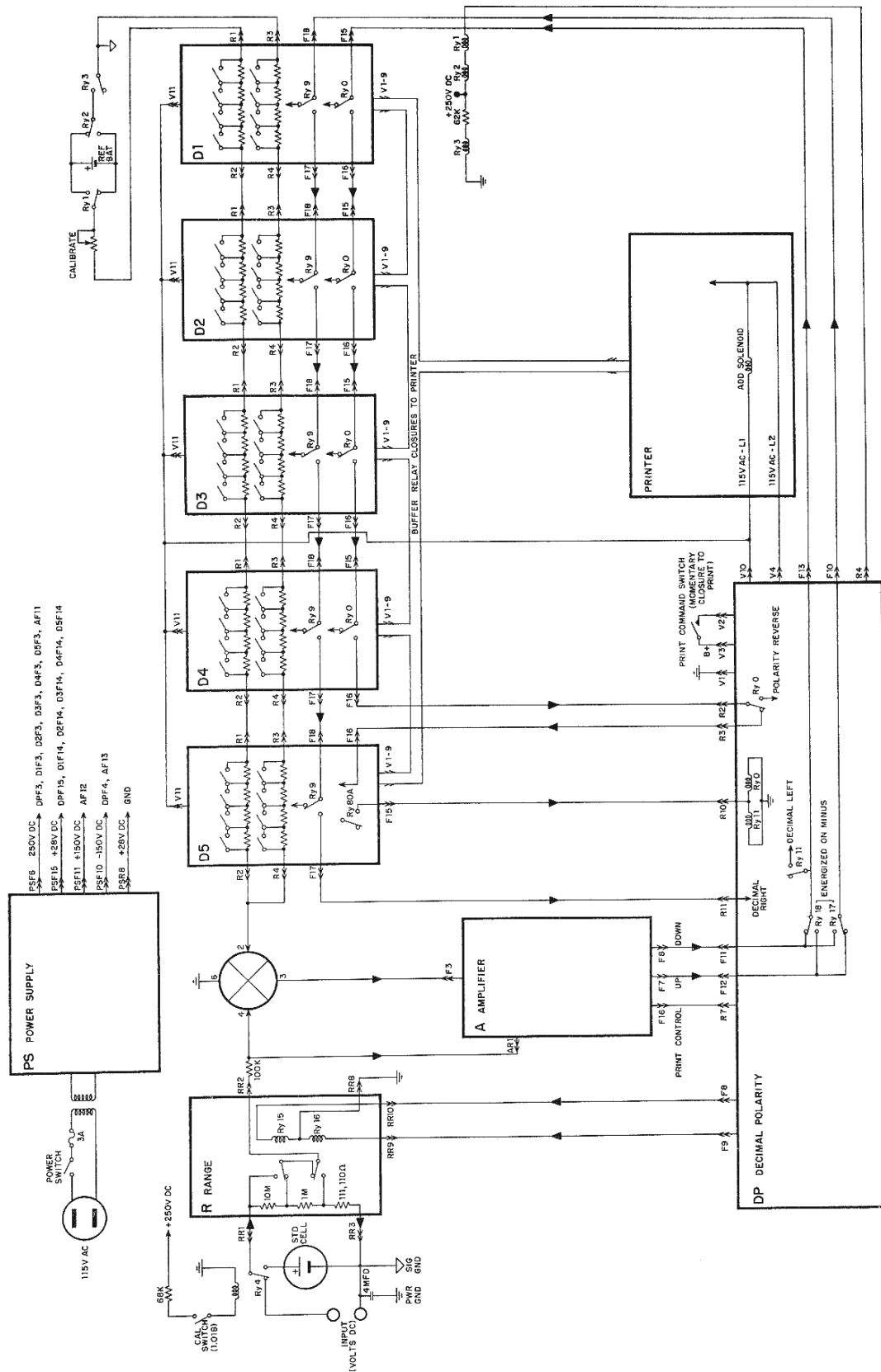
## OPERATION AND SERVICE MANUAL

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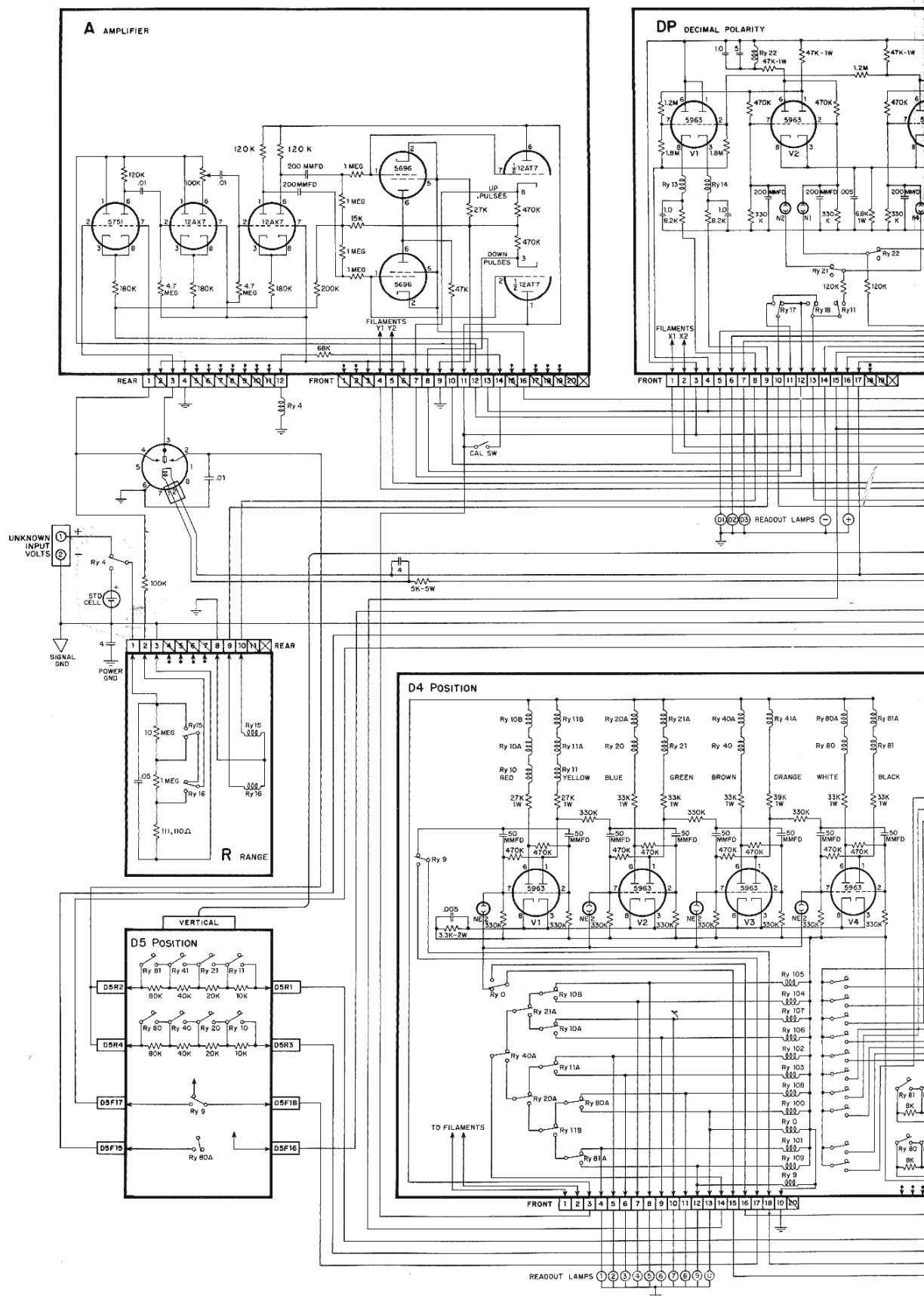
NOTES:



Figure 12 Digital Voltmeter Model 519-P Functional Diagram



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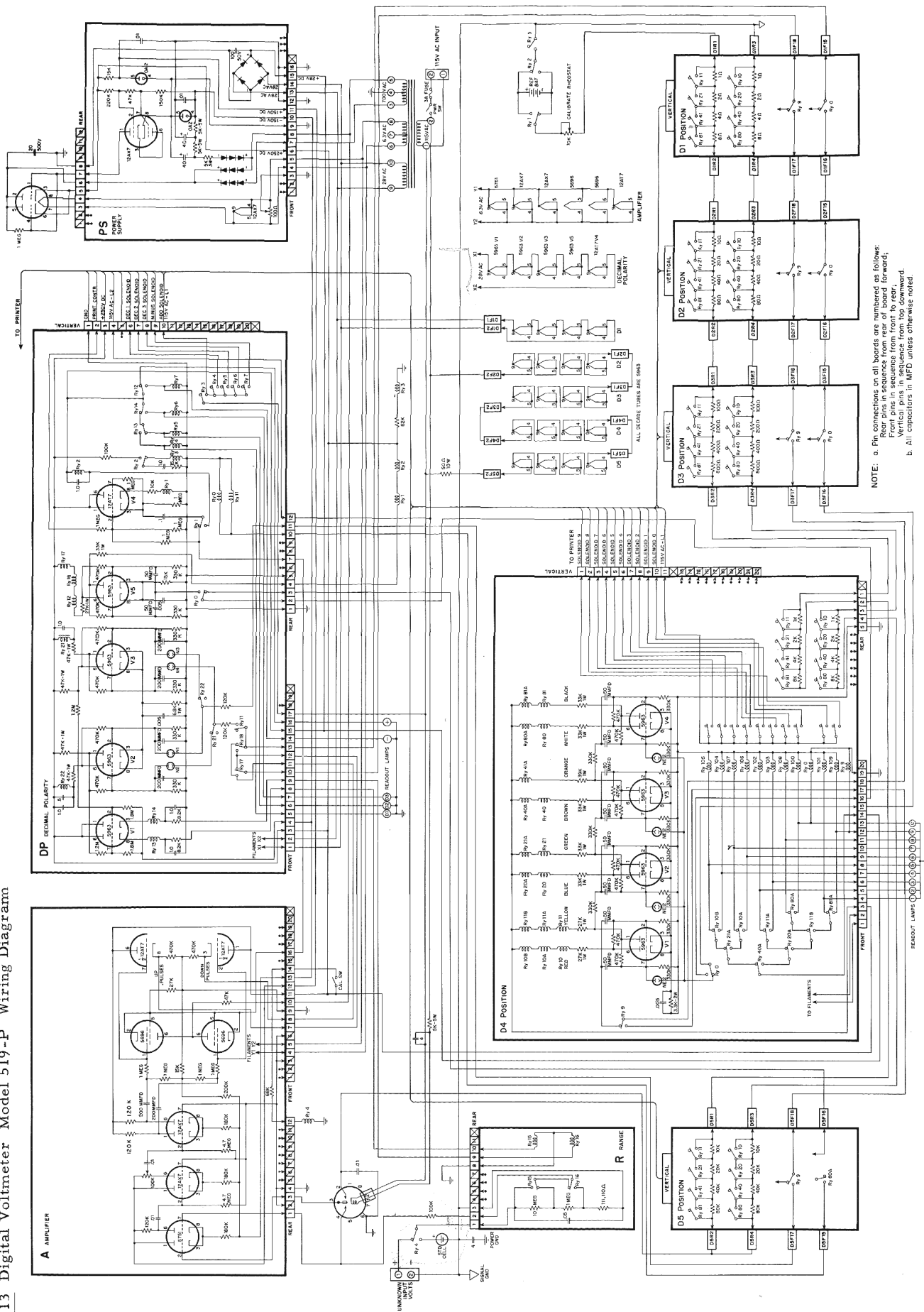


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Figure 13 Digital Voltmeter Model 519-P Wiring Diagram



NOTE: a. Pin connections on all boards are numbered as follows:  
 Rear pins in sequence from rear of board forward;  
 Front pins in sequence from front of board backward;  
 Vertical pins in sequence from top downward.  
 b. All capacitors in MFD unless otherwise noted.

Non-Linear Systems, Inc.  
Del Mar Airport,  
Del Mar, California, USA.

Instrument Type \_\_\_\_\_ Model # \_\_\_\_\_ Serial # \_\_\_\_\_

Your Order # \_\_\_\_\_ Our Invoice # \_\_\_\_\_

Date Shipment Received \_\_\_\_\_

Date of Inspection Report \_\_\_\_\_

Date Notice of Loss or Damage was Given to Carrier's Agent \_\_\_\_\_

Name of Carrier's Agent Receiving Notice of Loss or Damage \_\_\_\_\_

REMARKS  
(damages & etc.)

\_\_\_\_\_  
\_\_\_\_\_  
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IN CASE OF SHIPPING DAMAGE:

Fill out the above form and return it promptly with damage claim papers.

TO:

Non-Linear Systems, Inc.  
Del Mar Airport,  
Del Mar, California, USA.  
Telephone: SKyline 5-1135

DAMAGE REPORT (form no. 163)

INSTRUCTIONS

1. For proper compensation on shipping damages, take action immediately.
2. Give an immediate and a thorough inspection of shipment upon arrival.
3. Secure a notation on the freight bill for any damage or shortage noticeable on delivery. The carrier should sign this notation.
4. Unpack promptly and notify the delivering Carrier's Agent AT ONCE of any concealed damage or shortage, asking him to inspect the shipment and give you a signed inspection report.
5. Notice of LOSS or DAMAGE should be given delivering Carrier's Agent by telephone or in person and confirmed by mail within 48 hours, if impractical to inspect shipment immediately.

All goods of our manufacture are carefully inspected and shipped in packages approved by Consolidated Freight Classification. The Railroads and Motor Carriers are reluctant to make adjustment for damaged merchandise unless reported and inspected promptly after arrival. The Insurance Company does not cover any damage occurring after delivery, and delay in discovering concealed damage necessarily raises a question as to the time when the damage occurred.

6. After your report has been made to the carrier, fill out the form on the reverse hereof and forward this, with a copy of the signed inspection report to Non-Linear Systems, Inc., for appropriate action.

Claims for damage or missing parts are not allowed without supporting papers, and claims must be made within 10 days from receipt of shipment.

7. Please accept all shipments and write us before making any return shipment.

Your cooperation in complying with the foregoing will assist us in making prompt adjustment.

All equipment manufactured by Non-Linear Systems, Inc., is fully insured against damage incurred during shipping.